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# DYNAMO, MOTOR AND SWITCHBOARD CIRCUITS FOR ELECTRICAL ENGINEERS

A PRACTICAL BOOK DEALING WITH THE  
SUBJECT OF DIRECT, ALTERNATING  
AND POLYPHASE CURRENTS

BY

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## PREFACE.

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WHILE there are many excellent books dealing with the subject of Direct, Alternating and Polyphase Currents from a Theoretical, Mathematical and Text-book point of view, there are none, to the Author's knowledge, dealing with these subjects in a non-mathematical and practical standpoint on similar lines to those of this book.

The title of the volume indicates clearly what information is intended to be presented to the reader.

It is intended as a Practical Handbook for Electrical Engineers and Artizans.

It is not intended as a Theoretical Text-book; still, at the same time, it will be found useful for students preparing for the City and Guilds of London Examinations in Electrical Engineering, as it covers certain important sections of the Syllabus of the Ordinary and Honours Grades.

It would be practically impossible to give every and all connections and circuits applicable to these extensive branches of Electrical Engineering; but, in the Author's opinion, there are enough diagrams with explanations to generally cover the field.

The Introductory Section of the book gives certain information in a condensed form (which is not dealt with theoretically) as an explanatory section, so as to make the following sections clear and easily understood.

The Author has great pleasure in offering many thanks to Messrs. A. C. Eborall, J. R. Salter, and Ellis H. Crapper, for kind permission

to utilise extracts from articles written by them; he has also used as books of reference Mr. Tyson Sewell's "Elements of Electrical Engineering" (Crosby Lockwood), his own book on "Practical Construction of Electric Tramways" (Spon), and the excellent weekly periodicals, the *Electrical Review* and *Electricity*. For any extracts taken from the above, he tenders sincere thanks to the authors, editors, and publishers of the same.

W. R. B.

1904.

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# DYNAMO, MOTOR AND SWITCH-BOARD CIRCUITS FOR ELECTRICAL ENGINEERS.

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## INTRODUCTION.

1.—A **Dynamo** is a machine which converts **mechanical energy** into **Electrical Energy**.

A **Motor** is a machine which converts **Electrical Energy** into **Mechanical Energy**.

2.—A dynamo and motor are mutually convertible; that is, a dynamo will act as a motor if supplied with electrical energy, and a motor will act as a dynamo if driven mechanically, or, in other words, the same piece of apparatus will act both as a dynamo and as a motor, which depends upon whether it is supplied with mechanical or electrical energy.

Generally, a well-designed efficient dynamo becomes a good motor when so used.

3.—Dynamoes may roughly be divided into two classes : first, those in which they supply a current of electricity, which flows in one continuous direction through the circuit external to the machine, these are known as **continuous** or **direct current generators** or **dynamoes** ; and secondly, those which supply a current which rapidly alternates or reverses its direction through the external circuit, these are known as **Alternating Current Generators**, shortly termed **Alternators**.

The variation of the E.M.F. during the rotation of the armature conductor over **one pair of poles** is termed a "**Cycle**"; the

D.

B

number of "cycles" or "periods" passed through in one second is termed the "periodicity" or "frequency" of the alternating currents.

4.—Alternating current machines are generally constructed with a multiple of pairs of poles, and are generally called "multi-polar machines." The object of this is to increase the "frequency" and E.M.F. of the machine without increasing the speed, because there is a practical limit as regards the safe speed at which moving masses of machinery may rotate or move; the larger the machine, the slower the speed.

As previously stated, the variation of E.M.F. during one revolution of the armature coil when passing over one pair of poles is called one "cycle"; by employing two pairs of poles, the number of "cycles" or the "periodicity" or "frequency" is doubled; with three pairs of poles it is trebled, with eight poles (four pairs) quadrupled, &c.

5.—To find the "frequency" or "periodicity" of an alternator, the number of revolutions per second must be multiplied by the number of pairs of poles; for example, if the speed of an eight-pole alternator is 600 revolutions per minute, this divided by 60 = 10 revolutions per second; it has four pairs of poles, therefore its frequency is  $4 \times 10 = 40$  cycles per second.

The frequencies of practical machines vary between about 25 to 120 cycles per second.

Now, each "cycle" consists of two alternations or reversals; therefore the number of alternations is equal to twice the number of cycles. In the above case, the number of alternations or reversals per second =  $2 \times 40 = 80$ .

6.—The following are some of the frequencies adopted in practice :—

|                         |     |     |          |     |                       |
|-------------------------|-----|-----|----------|-----|-----------------------|
| Niagara                 | ... | ... | ...      | ... | 25 cycles per second. |
| Westinghouse Company    | ... | ... | 25 to 60 | " " | " "                   |
| Dublin Electric Tramway | ... | ... | 30       | " " | " "                   |
| Brown, Boveri & Co.     | ... | ... | 40       | " " | " "                   |

|                                   |     |                       |
|-----------------------------------|-----|-----------------------|
| Ganz & Co., of Buda-Pesth ...     | ... | 42 cycles per second. |
| The Allgemeine Electricitäts-     |     |                       |
| Gesellschaft, Berlin ...          | ... | 50 " " "              |
| Oerlikon Maschinenfabrik ...      | ... | 50 " " "              |
| General Electric Company, America | 60  | " " "                 |
| Different companies in Great      |     |                       |
| Britain ...                       | ... | 25 to 100 " " "       |

It will be seen from the above list that there is a very wide range in the number of "cycles" per second between the "minimum" and "maximum" periodicity adopted by different manufacturers. This is a great disadvantage, considered both from a commercial and practical standpoint. With a view to standardising the electrical pressures and frequencies of electrical machinery, there has recently been appointed an Electrical Engineering Standards Committee, for the purpose of discussing the *pros* and *cons.* of this important subject. The following are their recommendations on standard direct current pressures and standard frequencies :—

(1.) That the standard direct current pressures, measured at the consumers' terminals, be **110, 220, 440, and 500 volts.**

(2.) That the standard direct current pressures, measured at the terminals of the motors, be—for **tramways, 500 volts**; for **railways, 600 volts.**

(3.) That **25 periods per second** be the standard "**frequency**" for—

(a.) Systems involving conversion to direct currents by means of rotary converters.

(b.) Large power schemes over long distances.

(c.) Three-phase railway work, where motor gearing and the inductive drop on the track rail have to be considered.

(4.) That **50 periods per second** be the standard "**frequency**" for—

(a.) Mixed power and lighting on town supply mains.

(b.) Ordinary factory power plant.

(c.) All medium-sized power plant where rotary converters are not employed.

The importance of this standardising of conditions both from a manufacturing, commercial, and practical standpoint cannot be overestimated.

#### 4 DYNAMO, MOTOR AND SWITCHBOARD CIRCUITS.

7.—In dynamo machine design there is a fundamental formula connecting the number of lines of force of the magnetic circuit, the number of revolutions per second, the number of conductors around the armature, and a constant  $10^8 = 100,000,000$ . From these we can get  $E$ , the E.M.F. in volts.

Let  $N$ . represent the total number of lines of force.  $C$ . = conductors around armature,  $n$  = the number of revolutions per second. Then

$$E. = N. \times \frac{C. \times n.}{10^8}$$

$10^8$  is a constant, and is the relation between the absolute or fundamental unit and the practical units of E.M.F.

The above formula explains why it is that we can obtain a greater E.M.F. by increasing the number of lines of force without increasing the speed, and if we wish to obtain the same E.M.F. and reduce the speed, we can do it by increasing the magnetic lines of force round the magnetic circuit.

8.—There are simple “single phase” alternators, also “multi-phase” or “polyphase” alternating currents.

If we have two alternating currents whose “phase” difference is one fourth of a period, or one current lags behind the other 90 degrees, they are said to be in “quadrature,” and this constitutes what is technically termed a “two-phase” or “diphase” current; if we have three alternating currents which differ one third of a period in phase or have a relative phase difference of 120 degrees, they are known as “three-phase” or “tri-phase” currents. We may also have “three-phase” currents which lag 60 degrees behind each other.

9.—Mean value of E.M.F. and current in *alternators*.—In an alternator the voltage or E.M.F. in the outside circuit does not reach either the “maximum” or “minimum” amount which it attains in the armature, but rather an average or a mean value, which, under the most favourable conditions, is about  $\frac{1}{10}$  of the “maximum” value which the E.M.F. reaches in the armature. The current strength is proportional to the E.M.F.; therefore its average current strength in the external circuit is about  $\frac{1}{10}$  of the

"maximum" current in the armature. These are called "virtual" volts and amperes.

10.—To determine the power furnished by a continuous current dynamo, we can obtain it by measuring the volts by means of a voltmeter, the amperes by an ammeter; and multiplying the two together gives us the power in watts. But in the case of alternating current machines we have effects due to the influence of "**self-induction**" and "**capacity**" of the circuit, which makes it that the current flowing at any given time may be the result of an E.M.F. which existed some interval of time before or after that time.

11.—The "**actual power**" measured at any time is the number of volts multiplied by the number of amperes given off at that time, while the power obtained by multiplying the average voltage by the average current is always greater than the **actual power**, and is termed the "**apparent power**." Now, dividing the "maximum" value of the **actual power** by the **apparent power**, we obtain the "**power factor**" of the alternating current circuit.

Example.—To find the power factor when the actual power, as indicated by a watt meter, is 8,000 watts, and the average E.M.F. measured by means of a voltmeter, 100 volts, and the average current, measured by an ammeter, is 100 amperes; the apparent power is  $100 \times 100 = 10,000$  watts.

$$\therefore \text{power factor} = \frac{8,000}{10,000} = .8, \text{ or } 80 \text{ per cent.}$$

12.—There are **two properties** of a circuit which have certain actions in relation to alternating currents. These are the effects of "**self-induction**" and "**capacity**." The effect of "**self-inductance**" in a circuit is to **decrease** and **impede** or **retard** the current. Every circuit possesses more or less "**capacity**," and is a **condenser**; the effect of "**capacity**" is to **increase** and **accelerate** or **lead** the current before the E.M.F. Therefore an alternating current flowing in a circuit possessing considerable "**self-inductance**" will **lag** or **fall** behind the impressed E.M.F. causing it, and when traversing a circuit having considerable "**capacity**" will be in the "**lead**" or travel in front of the

impressed E. M. F. causing it. We can, therefore, by inserting into a circuit possessing **self-inductance** a **condenser** of suitable **capacity**, cause the **impedance** to be diminished and the current strength **increased**, and also by inserting a piece of apparatus possessing **self-inductance**, such as a **choking** or **impedance coil**, cause the **impedance** to be increased and the current strength **diminished**. We see that **inductance** and **capacity** produce **opposite** effects, and can be used to **neutralise** each other's effects. By suitably choosing a **capacity** and **inductance** of equal amount, the current neither **lags** nor **leads**, and the current is said to be in phase with the E.M.F.

13.—In addition to the above-mentioned apparatus, there are **transformers** which transform alternating currents from one voltage to another. If the alternating current is increased in voltage, it is called a **step-up transformer**; and if the voltage is lowered or decreased, it is called a **step-down transformer**. The principle of transformation depends upon **mutual induction**, and a **transformer** consists simply of a **laminated magnetic iron circuit** to form a good permeable path for the magnetic lines of force over which two separate coils of wire are wound; these are called the **primary** and **secondary circuits** or windings. In the case of the **step-up** transformer the **primary** consists of a comparatively few turns of thick well-insulated copper wire, and the **secondary** circuit of a great many turns of fine well-insulated copper wire; in the **step-down** transformer it is **vice versâ**. That circuit is called the primary circuit to which the terminals of the inducing current are connected, and the secondary circuit is the circuit in which the current is induced by the mutual induction due to the primary current.

14.—The **ratio of transformation** is the ratio of the transformed to the original voltage, and theoretically depends upon the ratio of the number of turns of the primary and secondary windings. If we wish to transform down from 2,000 volts in the primary to 100 in the secondary, the ratio of transformation is 20 to 1, and the comparative number of turns on the primary and secondary would be as 20 to 1.

The current increases and decreases in the same ratio as the voltages decrease and increase (neglecting stray losses).

For transforming continuous currents from one voltage to another, a machine called a **motor-generator** is used. It is a combination of a motor and a dynamo, generally combined together in the form of one single machine which has two separate windings on the armature, with a commutator and pairs of brushes at each end. The number of conductors in the **primary** and **secondary** windings are proportional to the ratio of the incoming and outgoing voltage, and the cross-sectional area of the armature conductors are in the inverse ratio, because the current strength is transformed inversely as the voltage.

15.—To transform alternating currents to direct or continuous currents, and *vice versa*, we use what are called **rotary converters**, which is a piece of apparatus equivalent to a combined direct current dynamo and an alternator, one winding in combination with the magnetic field, acting as a motor to drive it, the other winding (armature) acting as a dynamo or generator.

16.—A "**Booster**" is a dynamo driven mechanically (usually by means of a separate motor) to the terminals of which is connected a source of supply of a current at a certain voltage, and by means of the "**Booster**" its voltage is raised from its original voltage to any desired voltage. For example, it can be used to raise the voltage of a source of supply from 100 volts to 150 volts, &c. Boosters are generally used in combination with storage batteries on electric light and traction circuits.

There are "**Battery-charging Boosters**," "**Feeder Boosters**," "**Balancer Boosters**," &c.

A "**reversible**" **Booster** either adds to or subtracts from the line voltage.

"**Balancers**" or "**Equalisers**" are motor dynamos with equal windings. They are used to keep balance between the two sides of a three-wire system.

17.—There are **single-phase alternating current motors**, called **synchronous motors**, because they work in **synchronism** with the generator. They have two great disadvantages: (1) they are not self-starting, and must be brought up to the proper speed

before being connected in circuit; and (2) their field magnets must be separately excited.

**Two-phase** (diphase) **Motors** and **Three-phase** (triphas), **Motors** (polyphase current motors), the principle of action of which depends upon a rotating or rotatory magnetic field, are self-starting, and are called "**asynchronous motors**." There are two chief parts composing the apparatus, one part at rest, called the "**stator**," the other part rotating, called the "**rotor**."

**18.—Synchronous and Asynchronous.**—Both **single-phase** and **polyphase motors** may be divided into two distinct classes, *i.e.*, "**synchronous**" and "**asynchronous**" motors. The synchronous motor is one which runs perfectly "**in step**," or "**phase**," or synchronism with the alternating current supplied and consequently runs at a constant speed. The "**asynchronous**" motor does not run in synchronism with the alternating current supplied. Any alternating current generator can be run as a synchronous motor. The single-phase synchronous motor is simply a single-phase alternator reversed, which when its armature is supplied with an alternating current, and once run up to a constant speed, so as to be in synchronism with the generator and has its field-magnetism excited with a direct current, may be fully loaded and do work without being thrown out of synchronism. For long-distance transmission of power, and constant speed, and steady running with variable torque, the single-phase motor is perfectly adapted. There is a limit, however, to its use. (*a.*) It is not suitable for cases where the power has to be divided into separate and small units. (*b.*) It is not self-starting without special devices, as it has practically no initial torque. (*c.*) There is a limit to the load which it will take, and is liable to a sudden stoppage by a temporary overload, throwing it out of synchronism. The separate excitation by continuous current is also a disadvantage. Many devices, however, have been introduced to render this type of motor self-starting, and in this way its sphere of usefulness has been considerably enlarged. Another disadvantage is that it requires an auxiliary power for starting. On the other hand, it has certain advantages. Firstly, the speed of the motor is very constant and uniform, a property very desirable in certain cases, and secondly, the synchronous single-phase motor has a great advantage over all other alternating current

apparatus, in the fact that no phase difference between voltage and current is caused by it.

Owing to the above disadvantages, the two-phase and polyphase motors have become formidable rivals. The distinguishing features of the polyphase motors are—(1) the rotating magnetic field, and (2) the initial torque due to the inductive action of the closed or short-circuited armature coils or rotor. They are **induction motors**. They require no commutator, and unless a special starting resistance be used in connection with the “rotor” circuit, no slip rings are required, as there is then no connection between the external circuit and the rotor circuit. Without the starting resistance these induction motors have sufficient starting torque to enable them to start under load, and for general purposes they have a fairly high efficiency. Motors of this class are known as “**asynchronous motors**,” and they are so called because their working principle depends on the fact that they do not run synchronously; but their speed is less than the speed of synchronism.

The difference in amount between the armature speed of an “asynchronous” motor and the speed of rotation of the field is called the “**slip**.” The “**asynchronous**” motor is self-starting under load. The “**slip**” increases as the load increases. If the “**slip**” at half-load (half normal load) is  $1\frac{1}{2}$  per cent., it will be about 3 per cent. at full load. In practice a “**slip**” of from 2 to 5 per cent. is allowed.

We can get a **variation of speed** and **variable starting torque** by inserting **adjustable resistances** in the “rotor” circuit by means of slip rings.

19.—When two “**single-phase**” alternating current generators have to be run together in **parallel** to supply the same circuit as in lighting circuits they must be in **step** or in **synchronism** before they can be connected in **parallel**. It follows that the two alternators must be run at the same speed, generate an equal voltage, and be exactly in phase with one another. To indicate when one machine is in synchronism with the other machine a piece of apparatus known as a “**synchroniser**” is used.

## SECTION I.

### CONTINUOUS CURRENT DYNAMOS.

SERIES, SHUNT AND COMPOUND—CLOCKWISE AND COUNTER CLOCK-WISE ROTATION OF ARMATURE—STARTING—STOPPING, ETC.

1.—In dealing with continuous current dynamos or generators, we will only deal with those which are self-excited, with either the whole or part of the current generated in the armature conductors.

#### 2.—Series Wound Dynamo.

*Fig. 1* represents the above. The external circuit and field coil windings and armature are all in series with one another, and the

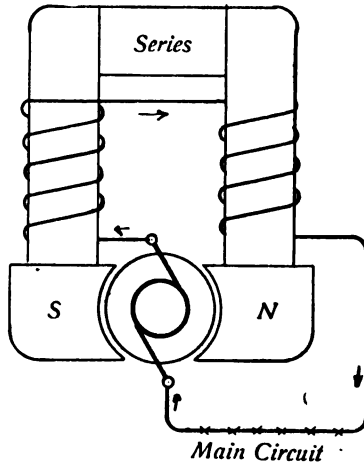


FIG. 1.—Series Wound Dynamo.

whole of the current which goes through the external circuit also goes through the field magnet coils. The field coils consist of a few turns of thick wire of comparatively low resistance. If the

external circuit is broken the field magnets receive no current, and the machine fails to generate any current.

### 3.—Shunt Wound Dynamo.

*Fig. 2* represents the above. The field magnet's windings or coils are composed of a great many turns of fine wire, and form a shunt to the external circuit; their circuit is independent of the external circuit, *i.e.*, the breaking or opening of the external or

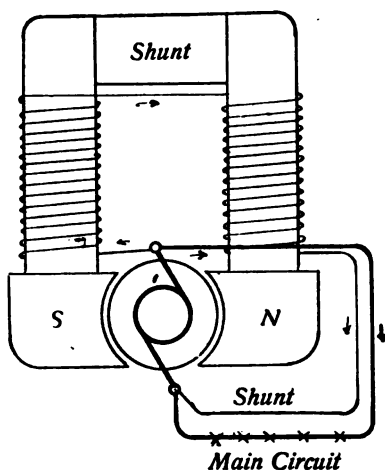


FIG. 2.—Shunt Wound Dynamo.

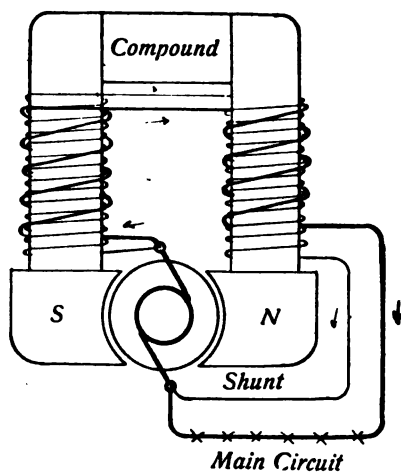


FIG. 3.—Compound Wound Dynamo.

main circuit does not open the shunt winding or field circuit. The field magnets take off only a small proportion of the whole current generated.

### 4.—Compound Wound Dynamo.

*Fig. 3* represents the above, which is a combination of the series and shunt windings, or is excited partly by the series coils and partly by the shunt coils. The object of compounding a machine is to obtain a constant voltage for incandescent lighting under variation

of load. Overcompounding consists in winding with additional series coils, the object being to maintain a constant voltage at a point in the circuit which is some distance away from the generating station.

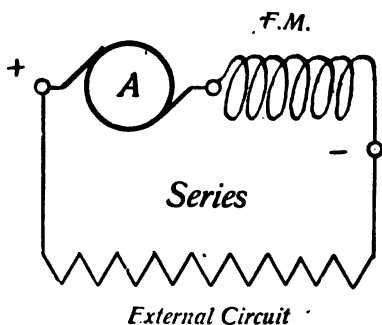


FIG. 4.—Series Dynamo Connections.

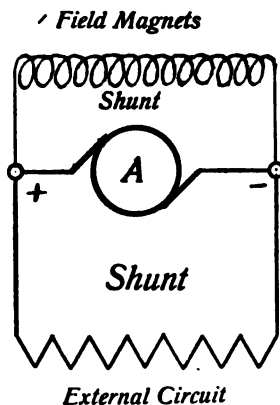


FIG. 5.—Shunt Dynamo Connections.

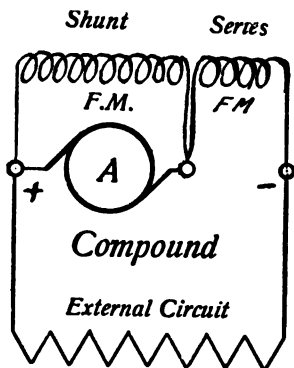


FIG. 6.—Compound Dynamo. Series and Short Shunt Connections.

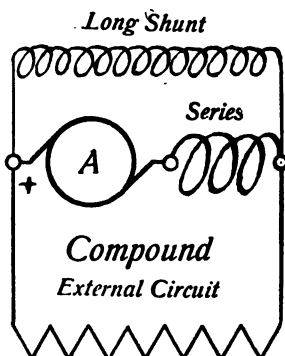


FIG. 7.—Compound Dynamo. Series and Long Shunt Connections.

### 5.—Series, Shunt, Short Shunt, and Long Shunt Compound Machines.

*Figs. 4, 5, 6, and 7 illustrate diagrammatically a series, a shunt, a short shunt compound, and a long shunt compound machine respectively.*

### 6.—Shunt Wound Dynamo on a Constant Potential Circuit supplying Incandescent Lamps in Parallel.

*Fig. 8 illustrates the above.*

*F.R.* represents the field regulating resistance coils. *A.* is the ammeter placed directly in series with the main circuit. *V.* is the

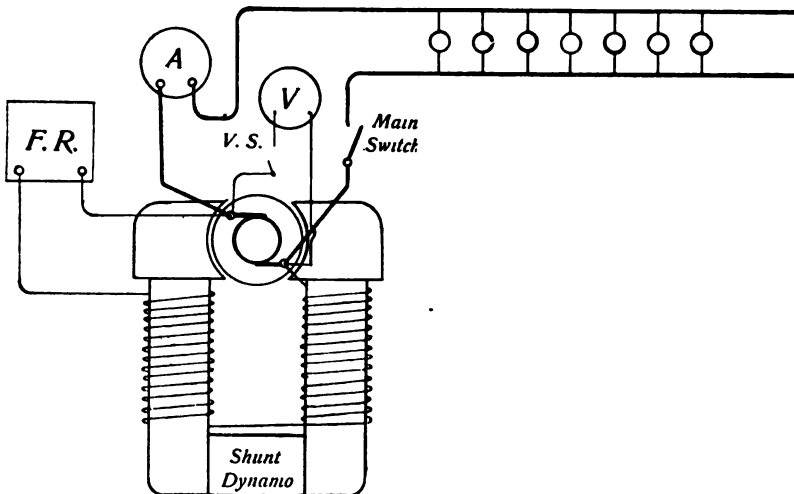


FIG. 8.—Shunt Wound Dynamo on a Constant Potential Circuit.

voltmeter, *V.S.* is the voltmeter switch; there is also a main circuit switch. To start the machine the main switch is open, it is then run up to its proper speed and voltage, and the main switch is then closed. The machine then supplies current to the main circuit. To keep the voltage constant the resistance in *F.R.* is varied. To stop the machine, if there is no chance of receiving current from any other dynamo or battery, it should be slowed down and stopped without opening the switches or lifting the brushes, after which the switches may be opened. Never open the main circuit or switch off at full or partial load except in case of emergency.

**7.—Series Wound Dynamo on a Constant Current (Variable Potential) Circuit with Lamps in Series (Arc Lamps).**

*Fig. 9* illustrates the above. The armature, main circuit, and ammeter are all in series. To start it the main circuit switch must be closed, otherwise it fails to generate; to stop, same directions as in par. 6.

**8.—Two Shunt Machines Connected in Parallel on a Constant Potential Incandescent Lighting Circuit.**

*Fig. 10* illustrates the above. The conditions are that the voltages of the two machines must be equal, but the current in

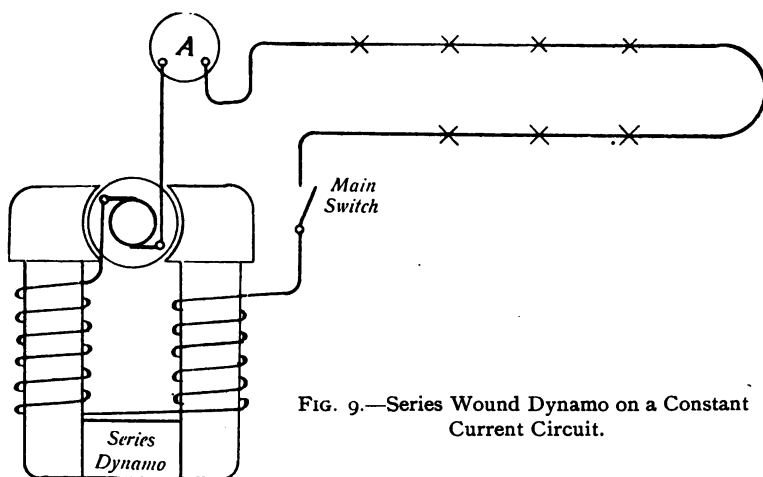


FIG. 9.—Series Wound Dynamo on a Constant Current Circuit.

amperes given off by each machine may vary; for instance, a 50-ampere machine may be connected in parallel with a 200-ampere machine, providing the voltages are equal. It is very important that a dynamo before being connected into circuit when other apparatus is already feeding it should be brought up to its proper speed and voltage, otherwise it may short-circuit the system and is very likely to burn out its armature; its voltage should be about 1 per cent. greater or higher than that of the circuit. To start the supply of current to the circuit, all the switches are opened, the machine No. 1 is run up to its proper speed and voltage, and then its main switch is closed. This feeds the circuit by machine No. 1. To introduce machine No. 2, run it up to its proper speed and

voltage (about 1 per cent. higher); then close main switch of No. 2 machine. To stop, open main switch of No. 2 (if only small demand

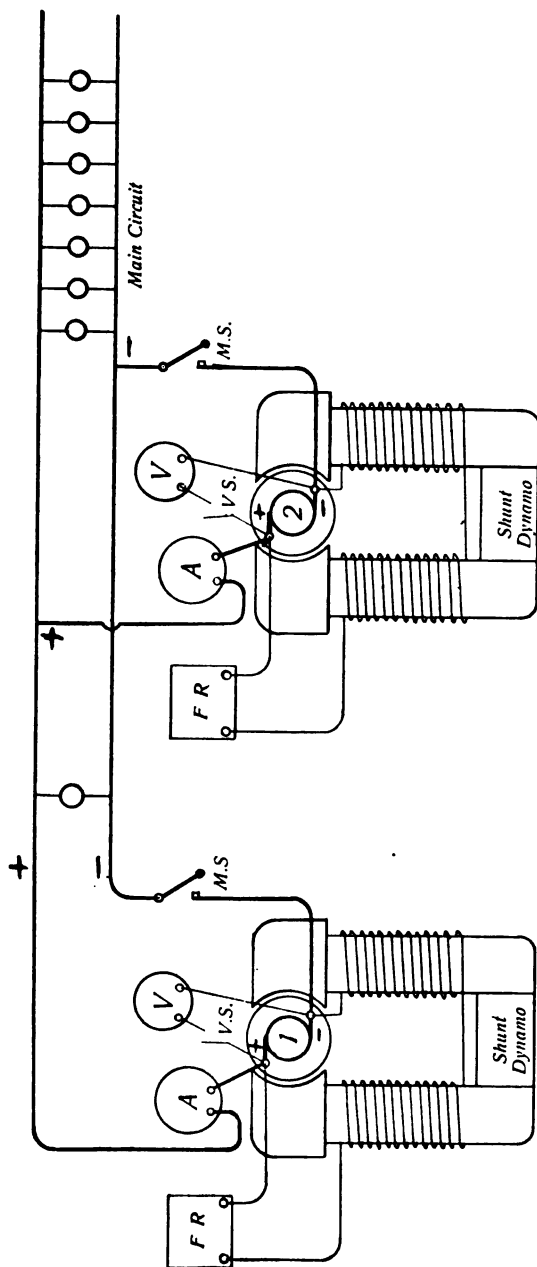


FIG. 10.—Shunt Dynamos in Parallel on a Constant Potential Circuit.

is on circuit), and then machine No. 1 can be slowed down, and its switch opened, or both machines can be slowed down together at equal speeds, and then the switches opened.

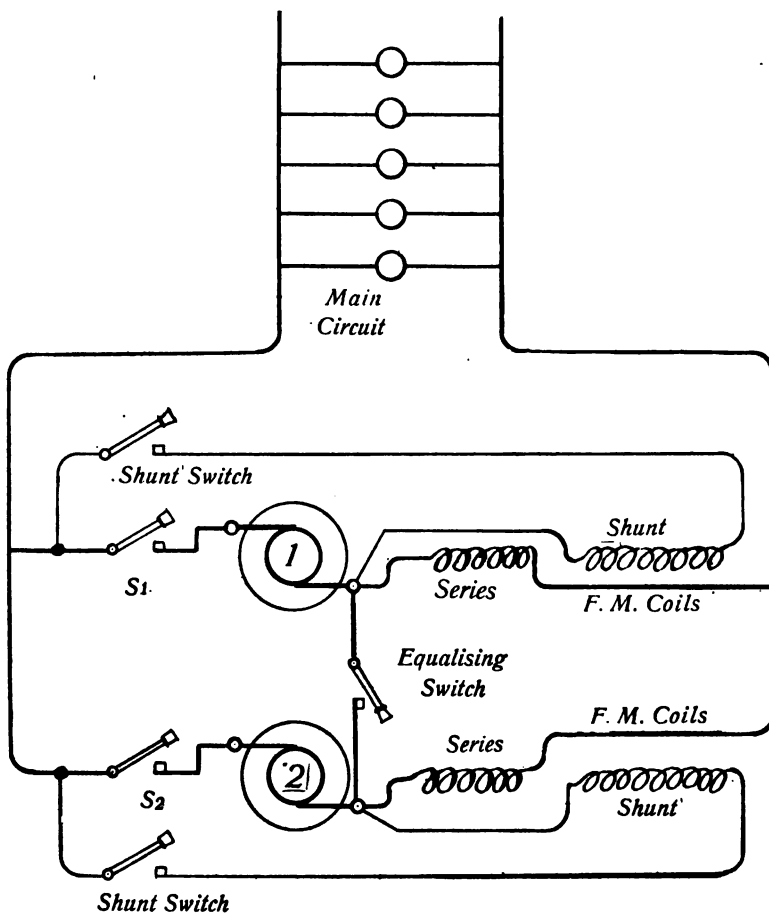


FIG. 11.—Compound Dynamos in Parallel on a Constant Potential Circuit.

**9.—Two Compound Wound Dynamos Connected in Parallel on a Constant Potential Incandescent Lighting Circuit.**

Fig. 11 illustrates the above. A compound machine is a combination of a series and shunt field winding, and we require switches both in the series main circuit and also in the shunt circuit.  $S_1$  is

the series switch of dynamo No. 1, and  $S_2$  is the series or main switch of machine No. 2; there is in addition an equalising wire and switch, which short-circuits the same polarity brushes of the two machines; its object is to keep the voltages of the two armatures equal, also the currents in two series windings are equal. To place machine No. 1 in circuit, close shunt coil switch and switch  $S_2$ ; then run up the speed and voltage, when at the proper speed the proper voltage will be attained. To introduce machine No. 2, close shunt switch of No. 2; run up to proper speed and voltage; then close the

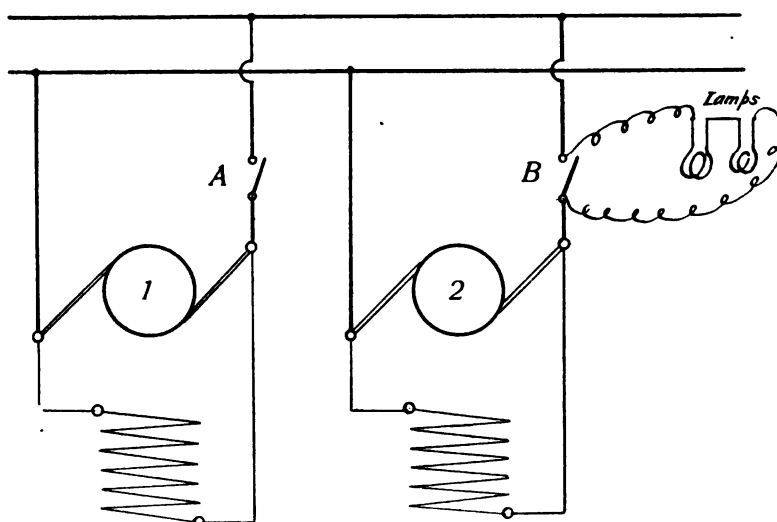


FIG. 12.—Testing Polarity of Dynamos. Lamp Method.

“equalising switch,” and then main series switch  $S_2$ . To stop the machines, reverse operations.

#### 10.—Methods of Securing Right Polarity of Dynamos.

When a dynamo has to be inserted in a circuit, and run in parallel with either a secondary battery or another dynamo, it is important to be certain that the leads are of the right polarity. If by accident the positive of one machine was connected to the negative of the other they would not be connected in parallel, but in series. To test the polarity proceed as follows: run both machines up to the same voltage; then close the switch  $A$ , of machine No. 1 (*Fig. 12*);

D.

C

then connect the terminals of two series connected normal voltage lamps with the terminals of switch *B*. of machine No. 2 (switch *B*. must be left open). If the polarity of both machines is all right, then the lamps will not glow; but if connected in series, the lamps will brightly glow with their proper voltage. This indicates that the

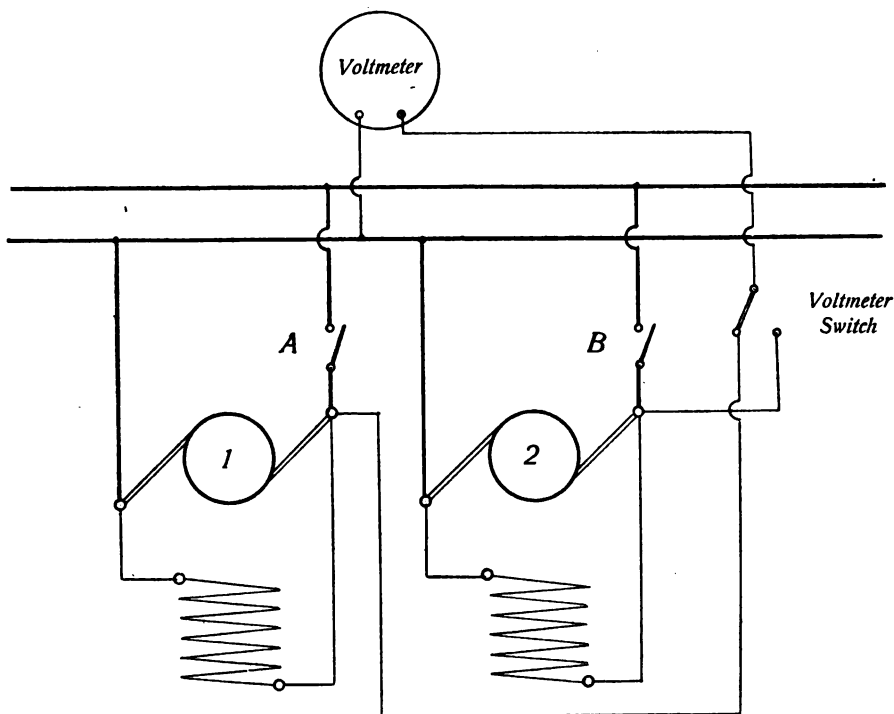


FIG. 13.—Testing Polarity of Dynamos. Voltmeter Method.

machines are wrongly connected. The machines must then be stopped, and the leads of one machine reversed.

Another method of finding the right polarity is indicated in *Fig. 13*. Connect a "voltmeter" as indicated. Have both machines running up to proper speed and voltage. Now close the "voltmeter" switch, so that it indicates the voltage of first machine 1, then machine 2. If the pointer of the "voltmeter" is deflected in the same direction in each case, then the machines are of the same polarity; if it is

deflected in opposite directions, then the machines are connected up of opposite polarity. If wrongly connected, proceed as in the previous case.

## 11.—Polarity of a Machine.

It is important sometimes to know which is the positive pole of a dynamo. This can be found by means of pole-finding paper. It is made of paper which has been soaked in a chemical substance. When the paper is wetted and included in a circuit the end of the paper which is connected to the positive pole becomes discoloured a certain colour. This is due to "electrolytic" action. A very simple

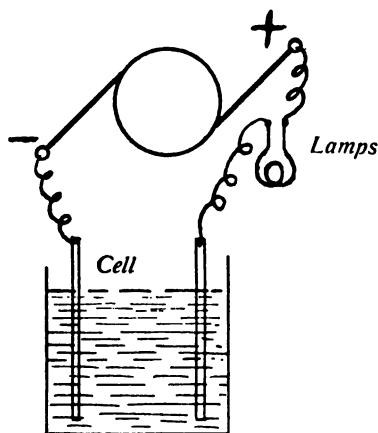


FIG. 14.—To find Positive Pole of a Direct Current Dynamo.

means of ascertaining which is the positive pole of a continuous current dynamo is to take two clean strips of metallic lead, place them side by side in a non-metallic vessel, fill up the vessel with a dilute solution of sulphuric acid and water (about 1 part  $\text{H}_2\text{SO}_4$  to 10 of water), and connect this in circuit through a lamp with the terminals of the dynamo. The lead plate connected to the positive pole of the machine will, after a few minutes, become of a **dark chocolate brown colour**, due to the formation of **peroxide of lead**. The connections are indicated in *Fig. 14*.

**12.—Effects of Changing the Direction of Rotation of the Armature.**

We must connect the magnet coils with the armature brushes in such a manner that the current from the armature flows through the

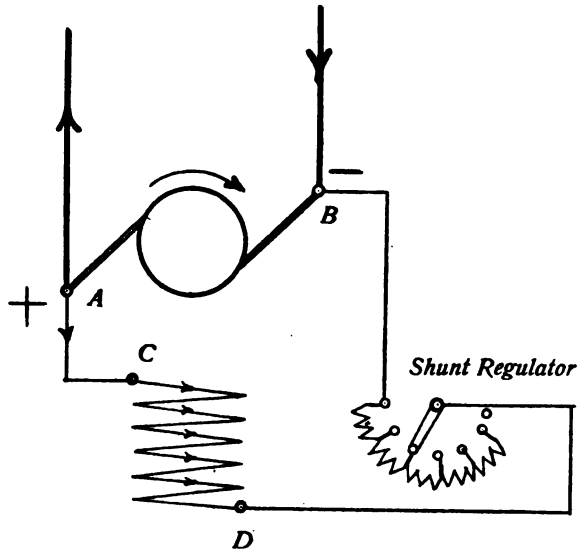


FIG. 15.—Clockwise Rotation of the Armature in a Shunt Dynamo.

field magnets in such a direction as to strengthen the field magnetism.

**13.—Shunt Dynamo: Clockwise Rotation of Armature.**

*Fig. 15* illustrates a shunt machine in which *A.* and *B.* represent the brush terminals, *C.* and *D.* the field magnet terminals, and also the shunt-regulating resistance.

In the figure it will be seen that the *C.* connection is connected to *A.* terminal, and that the positive current flows downwards from *C.* to *D.* in such a direction as to strengthen the field magnetism. The arrowheads indicate the direction of flow of the current both in the external circuit and the field magnet circuit.

**14.—Shunt Dynamo: Counter-clockwise Rotation.**

On referring to *Fig. 16*, it will be seen that if the direction of rotation is now reversed, that the *A.* brush now becomes negative (owing to the reversal of the current), whereas in the previous case it was positive. The result is that if left connected to *C.*, as in the previous case, the current would flow through the field magnet coils from *D.* to *C.*, or in the opposite direction to what it flowed in the previous case. The effect of this would be to destroy its original

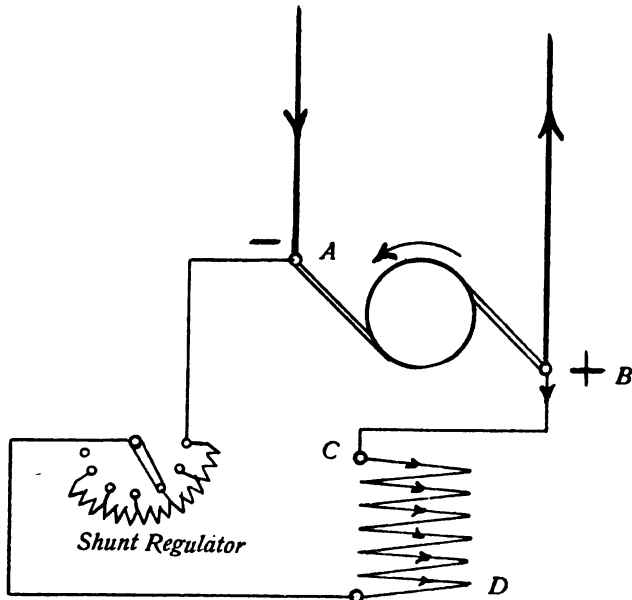


FIG. 16.—Counter-clockwise Rotation of the Armature in a Shunt Dynamo.

magnetism. For this reason we have to connect terminal *C.* to terminal *B.* (as shown in *Fig. 16*), and it will be seen, although the current now flows through the external circuit in the opposite direction to what it did before, that it flows through the field magnets in the same direction. This is exactly the condition required.

**15.—Series Dynamo: Clockwise and Counter-clockwise Rotation of Armature.**

On referring to *Figs. 17* and *18*, it will be noticed that the field connection at *C.* has to be reversed from positive terminal of brush *A.*

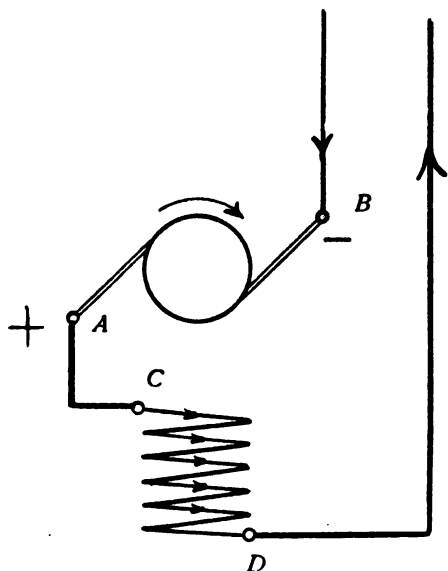


FIG. 17.—Clockwise Rotation of the Armature in a Series Dynamo.

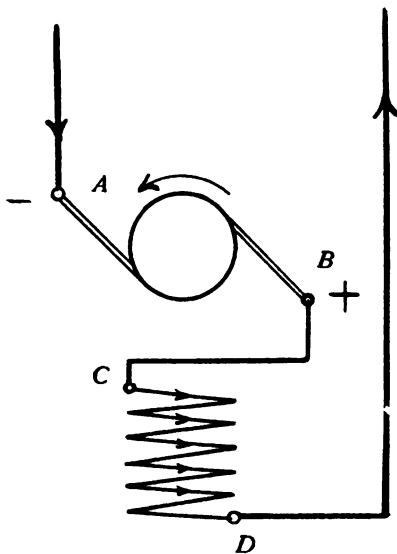


FIG. 18.—Counter-clockwise Rotation of the Armature in a Series Dynamo.

(in *Fig. 17*) to positive terminal of brush *B*. when the direction of rotation is reversed (*Fig. 18*).

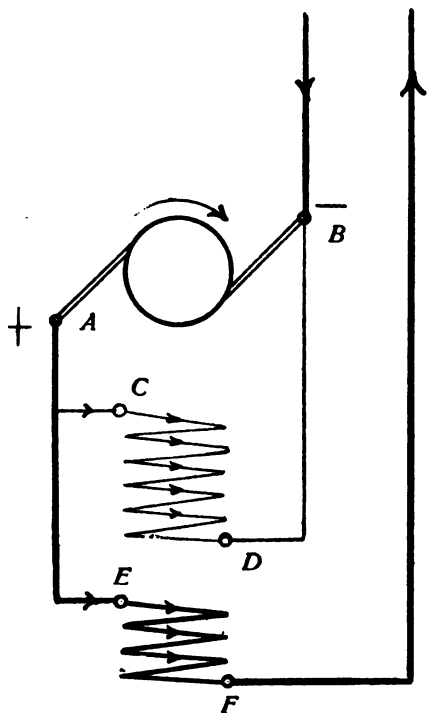


FIG. 19.—Clockwise Rotation of the Armature in a Compound Dynamo.

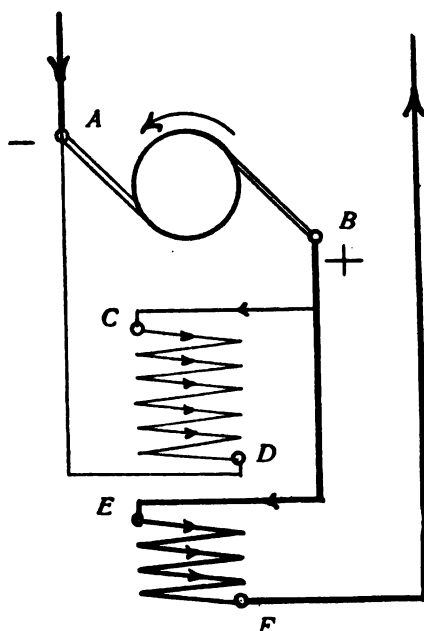


FIG. 20.—Counter-clockwise Rotation of the Armature in a Dynamo.

# 16.—Compound Dynamo: Clockwise and Counter-clockwise Rotation of Armature.

In this arrangement, we must change over both the shunt (*C.*) and series (*E.*) field magnet connection from *A*, brush terminal (*Fig. 19*) to positive *B*, brush terminal (*Fig. 20*) when the direction of rotation is reversed.

## SECTION II.

### DIRECT CURRENT MOTORS.

SERIES, SHUNT AND COMPOUND—CLOCKWISE AND COUNTER-CLOCK-  
WISE ROTATION OF ARMATURE—SPEED REGULATION.

#### 1.—Constant Potential Motor (Shunt-wound) on a Constant Potential Circuit.

*Fig. 21* illustrates the above. This is the commonest form of stationary motor, and will run at constant speed on a constant potential circuit. The field magnet coils are wound with the right

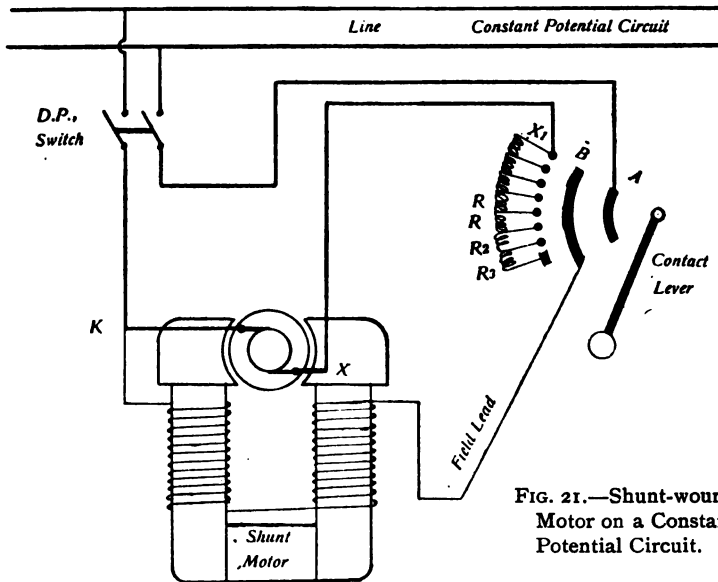


FIG. 21.—Shunt-wound  
Motor on a Constant  
Potential Circuit.

size of wire to take the proper magnetising current, and if the potential is constant the field strength will be constant. In connecting the motor in circuit, the field coils must be placed in circuit first, so that there is a certain amount of field magnetism, whereby the mutual reaction between the field magnets and the armature current causes rotation of the armature, and thus keeps the current flowing through the armature of a safe amount. If the field magnets were not put in circuit first, the armature at rest on receiving current would probably burn out, because the armature is

of very low resistance, and would take practically all the current supplied; there would be practically none go round the field magnet coils, no mutual reaction, and no rotation of the armature. Therefore there is no counter-E.M.F. to keep back the excessive current. The apparatus and method of starting is shown in the sketch. There is a branch circuit taken off the mains or line through a double pole switch; the connections can be readily seen. To start the motor the double pole switch is closed. On pushing over

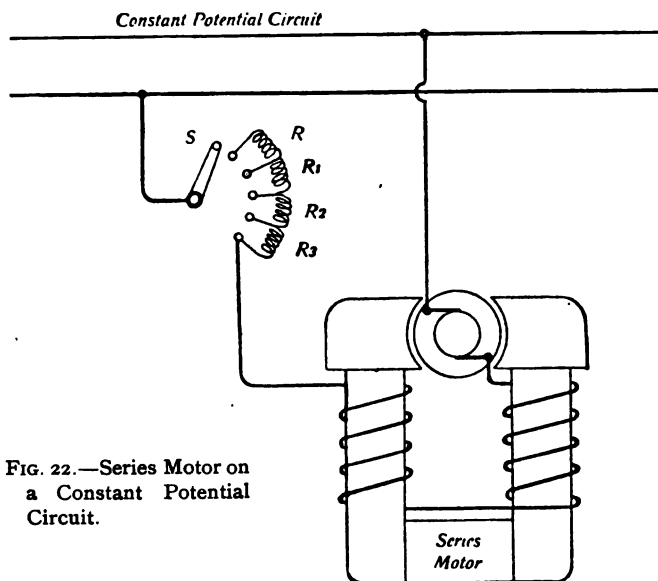


FIG. 22.—Series Motor on a Constant Potential Circuit.

the contact lever so as to make metallic contact with the circular arc sliding contact blocks *A.* and *B.*, it will be seen that the field leads are placed in circuit first. This causes a suitable current to flow through the field magnets, and they become excited. On further rotating the contact lever, it places in circuit the armature through the resistance coils *R.*, *R*<sub>1</sub>, *R*<sub>2</sub>, *R*<sub>3</sub>, &c., and as the speed of rotation of the armature increases the resistances are gradually cut out until when in contact with *X*<sub>1</sub>, the starting resistance is completely short-circuited. To stop, reverse the operations.

## 2.—Series Motor on a Constant Potential Circuit.

*Fig. 22* illustrates the connections. This motor on a constant

potential circuit does not have a constant field strength, nor yet run at a constant speed. If the load is taken off entirely it will "race" and run at an excessive speed. The electric tramway motors are series-wound. They are only suitable where variable speed is required, such as for elevators, pumps, fans, and railway work. The machine is connected to the main circuit as shown. To start it, the

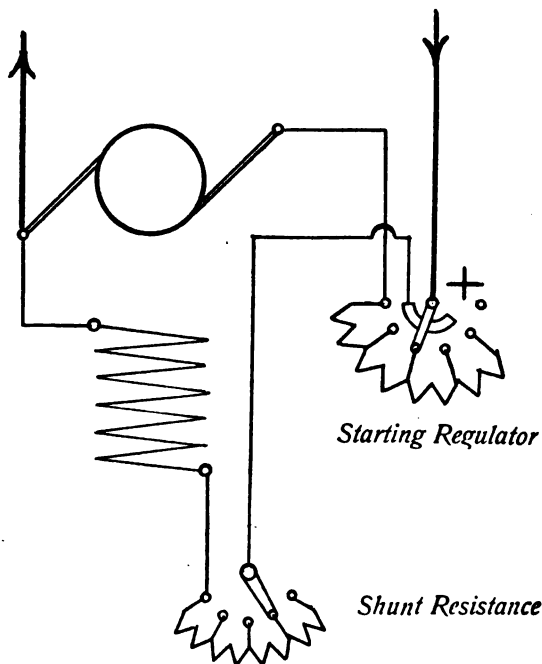


FIG. 23.—Speed Regulation of Shunt Motor.

circuit is completed through a starting resistance and switch *S*. *R*., *R*<sub>1</sub>, *R*<sub>2</sub> are the resistance coils. To stop, reverse the operations.

### 3.—Speed Regulation of Shunt Motor.

The speed of a motor depends on the voltage of supply and the strength of its magnetic field. The motor tends to rotate so fast as to produce a back or counter-E.M.F. nearly equal to the terminal voltage. Therefore, if we double the terminal voltage, the motor will run with nearly double the speed. By decreasing the terminal

voltage of the motor we, therefore, decrease the speed of the motor. This reduction of speed may be brought about by inserting a resistance in series with the motor. By inserting this resistance in the field circuit, the voltage at the terminals of the motor is lowered, thus giving the condition necessary to reduce the speed. *Fig. 23* illustrates an arrangement for varying the resistance and speed in which we have a starting regulator and a shunt resistance regulator.

#### 4.—Short Circuiting Device for the Magnet Coils, with Shunt Regulator.

When a shunt circuit is broken, a much longer spark results than in the case of a lamp circuit of equal current strength and voltage.

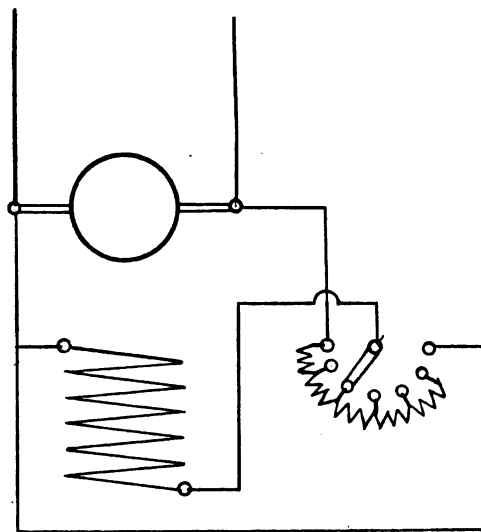


FIG. 24.—Short Circuiting Device for the Magnet Coils.

This is due to an effect called “**self-induction.**” Thus when we break a shunt circuit a spark occurs, which results in the burning away of the contact slip rings and the brushes of the starter. To avoid this, the shunt circuit should never be broken with a current on. A sparkless breaking of the motor circuit can only be effected if there is at the moment of switching out no, or a very small, pressure difference between the starting lever and the last contact. Sometimes it is impossible to avoid the interruption of the shunt

circuit. In *Fig. 24* is shown an arrangement to overcome the difficulty in the case of a dynamo. It consists in closing the shunt circuit on itself whilst it is being switched out, so that the "self-induction" current may flow in the circuit so formed. The switching out of shunt regulators must not be done suddenly, like the switching out of starters. It should be done gradually, in order that the voltage of the machine may decrease.

### 5.—Direction of Rotation of a Motor Armature.

To alter the direction of rotation of a motor armature, we have either to change the direction of the armature current, or to reverse

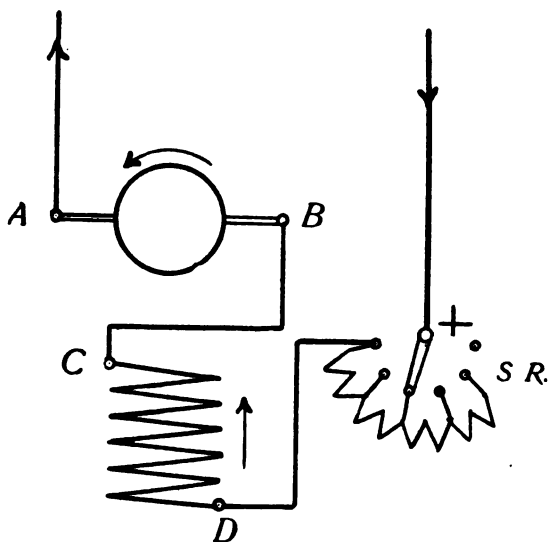


FIG. 25.—Counter-clockwise Rotation of the Armature in a Series Motor.

the polarity of the magnetic field (Field Magnets). If we reverse the armature current and the polarity of the field magnets simultaneously, the direction of rotation will of course, remain the same as before.

### 6.—Series Motor: Counter-clockwise Rotation of Armature.

In *Fig. 25* is shown the connections for a series motor which rotates in a counter-clockwise rotation. The positive direction of current flows from the starting lever and through the field magnet coils from *D.* to *C.*, and in the armature from brush *B.* to brush *A.*, to which is connected the negative pole of the feeder.

### 7.—Series Motor: Clockwise Rotation of Armature.

To reverse the direction of rotation of the armature, we may either allow the current to flow in its original direction (from *D.* to

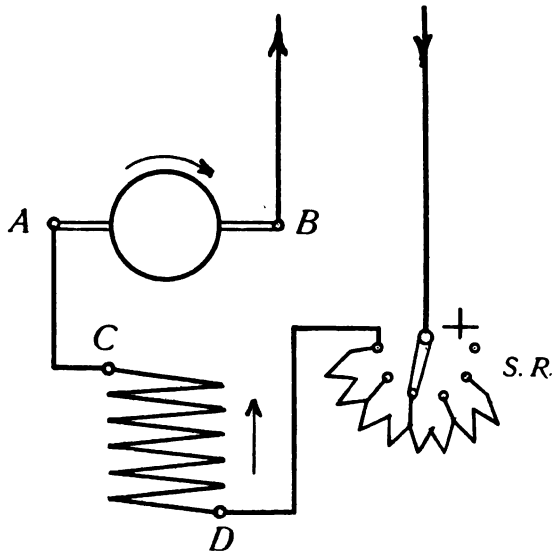


FIG. 26.—Clockwise Rotation of the Armature in a Series Motor.

*C.*) in the field magnet coils, and alter the direction of the armature current by changing the two connections on the brushes *A.* and *B.*, thus connecting field magnet terminal *C.* to brush *A.* and brush *B.* with the second feeder wire, as shown in *Fig. 26*, or we may leave the direction of the flow of current in the armature in its original direction, and reverse that of the field magnet current, as shown

in *Fig. 27*. If we changed the mains or feeders leading to the starter and to the motor directly, there would be no reversal of the direction of rotation of the motor armature, because by so doing both the armature and the field magnet current would be reversed.

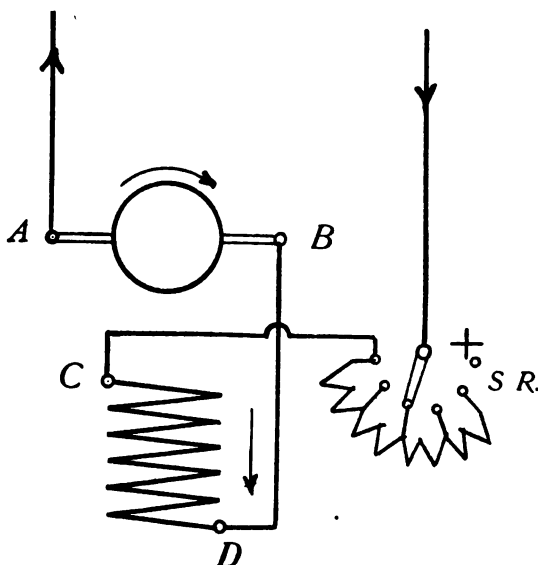


FIG. 27.—Clockwise Rotation of the Armature in a Series Motor.

#### 8.—Shunt Motor : Counter-clockwise Rotation of Armature.

*Fig. 28* shows the connections of a shunt motor in which the direction of rotation of the motor armature is counter-clockwise. The direction of the field magnet current is from *D*. to *C*., and the armature current from *B*. to *A*. The positive main or feeder is connected to the starter lever.

#### 9.—Shunt Motor : Clockwise Rotation of Armature.

To reverse the direction of rotation of the motor armature, the current may be allowed to flow in its original direction through the field magnet coils (from *D*. to *C*.), but in the reverse direction through the armature (from *A*. to *B*.), as shown in *Fig. 29*, or the direction of the flow of current through the field magnet coils may be reversed

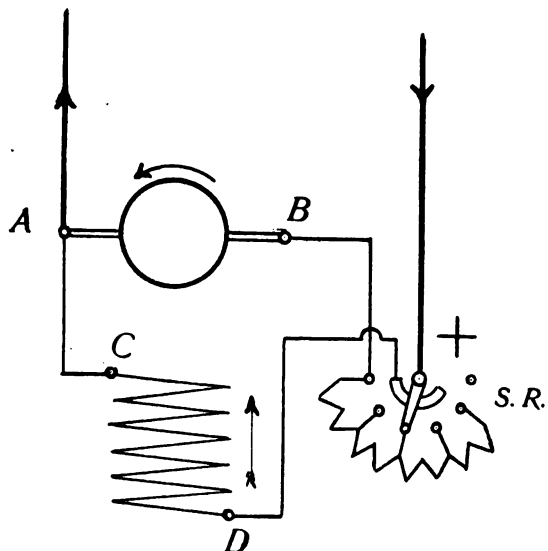


FIG. 28.—Counter-clockwise Rotation of the Armature in a Shunt Motor.

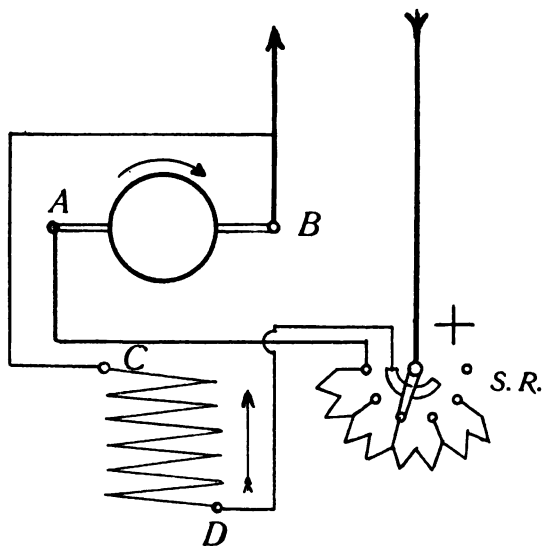


FIG. 29.—Clockwise Rotation of the Armature in a Shunt Motor.

(from *C.* to *D.*), and the armature current flow in the original direction (from *B.* to *A.*), as shown in *Fig. 30.*

#### 10.—Compound Motor.

A compound (series and shunt) winding of the field magnet coils (*Fig. 20*) may be used on motors for various purposes. If the current flows in the same direction through both the series and shunt windings, then the combined effects of the two windings will

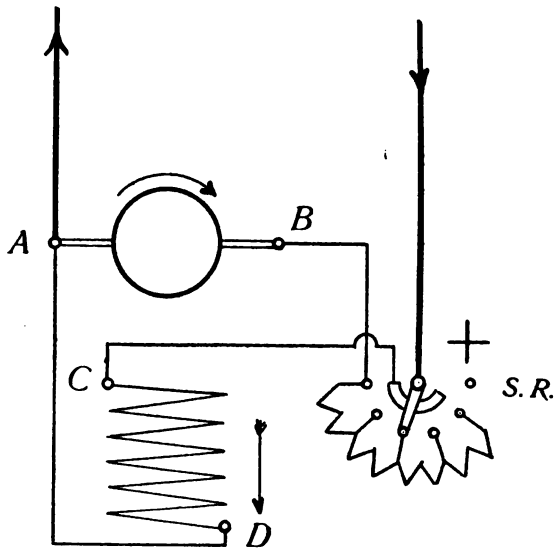


FIG. 30.—Clockwise Rotation of the Armature in a Shunt Motor.

be to strengthen each other, consequently also the field magnetism. This strengthening is greater the larger the armature current—*i.e.*, the heavier the load—because an increased armature current, of course, increases the current through the “series winding.” Thus the motor gets at increasing load a stronger magnetic field; and will, therefore, if the voltage remain constant, run slower than before. For a given current the starting power of the “compound” motor is greater than that of a “shunt” motor. With a decreasing load the motor will run faster. The motor cannot “run away,” however (the

same as a series motor), when the load is taken off entirely, because the "shunt" winding produces a magnetic field of sufficient strength to prevent it.

## II. — Differential Wound Compound Motor to Produce Constant Speed.

The speed of a "shunt-wound" motor does not remain absolutely constant at all loads. Generally it decreases a little at increased load. We may obtain a constant speed in a "compound motor" with "variable" load by means of a "differential" winding, which consists in so connecting the "series" and "shunt" windings that they act in "opposition." The result is that, as the load becomes heavier, the field of the motor is weakened, and the armature runs faster. On the other hand, the motor would run slower at an increasing load if it were a "shunt" motor only; this fall of speed is compensated by the action of the "series" winding. Thus a compound wound motor (differentially wound) is capable of giving a "constant" speed at all loads. Strictly speaking, this statement is not absolutely true, because we get a variation of speed which cannot be compensated by the series coil. This is due to the rising "temperature" of the motor. This "variation" of speed, due to temperature causes, can, however, be compensated by inserting a variable resistance regulator in the "shunt" circuit, as shown in *Fig. 23*.

## SECTION III.

### ELECTRIC TRACTION, CONTROLLERS, &c.

MOTORS, TRAMWAY CIRCUIT, SERIES-PARALLEL CONTROLLER, ELECTRIC BRAKE, WIRING DIAGRAMS, ACCUMULATOR CARS, ELECTRIC VEHICLES, &c.

#### 1.—The Series Motor.

For electric trams and motor cars series motors are employed with great advantage. The starting of an electric car can be effected more quickly with a "series" than with any other motor. The "series" motor exerts its greatest "power" or "torque" when most needed (*i.e.*, at starting). On "gradients" the car is running slower and does not require so much current as one equipped with a "shunt-" wound motor, whereas on the "level" the series motor enables the car to run with a far higher speed.

#### 2.—Diagram of Electric Tramway Circuit.

*Fig. 31* illustrates the method of transmitting electric power from the power house to the "overhead trolley line." Then the current goes through the controller and motor and the return "rail" circuit back to the power house or generating station. (Taken from the author's book "Practical Construction of Electric Tramways," Spon.)

#### 3.—Electric Tramway or Railway Motors and Controllers.

Electric street cars are generally equipped with two series-wound motors. The voltage of the circuit usually adopted is about 500 volts. To obtain "variations" in the "speed" and "torque," the motors are sometimes connected both in "series" across the circuit, and sometimes both in "parallel" across the circuit. The speed of a series motor depends upon its field strength; that is, it varies with its magnetising force or with the number of ampere turns on its field magnets. A method of regulating the speed is by changing the field coil connections; *i.e.*, the number of ampere turns

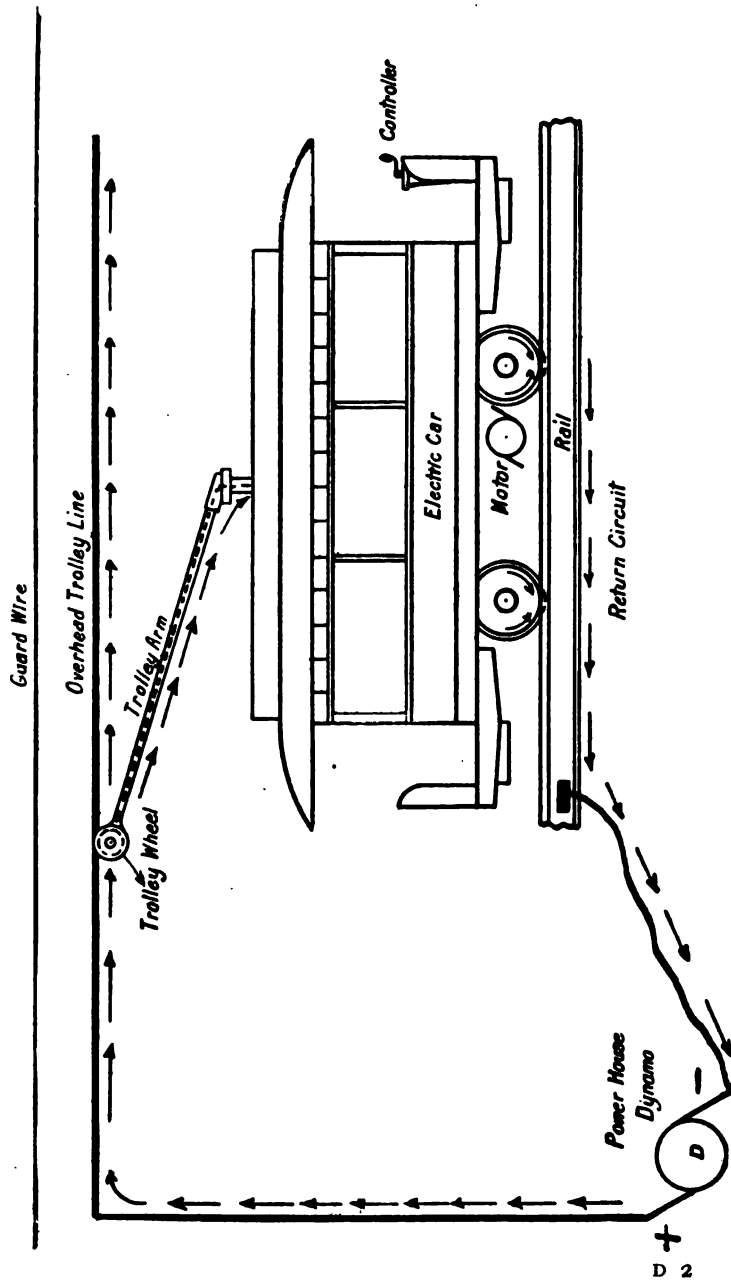


FIG. 31.—Electric Tramway Circuit.

is varied either by cutting out portions of the windings, or by the combination of the field coils in various ways. In the commuted field method, the field coils of the motor are wound in different sections, divisions, or coils (usually three). By connecting the field coils of the motors in different combinations the speed of the motors is thus controlled. This different combination of the field coil windings is effected by means of a controller or switch which consists of a barrel upon which are fixed brass strips of various shapes, and against these strips press spring contacts to make good electrical connections with the barrel strips. In the starting of an electric car it requires much greater force than is needed to keep it moving after it has once been set in motion. Therefore the motors at starting must be supplied with a comparatively heavy current. The

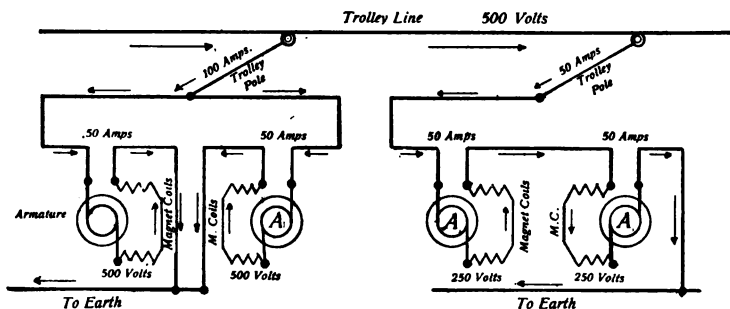


FIG. 32.—Series Motors on Electric Tramway Circuit.

turning power (torque) of a series motor depends only upon the strength of the current flowing through the armature circuit, and is independent of the voltage across its terminals. If the two motors are connected in one circuit, as in *Fig. 32*, with a current of, say, 50 amperes flowing through the two motors in series, they will give the same starting effect or torque as 100 amperes flowing through the two motors in parallel; therefore by connecting the two motors in series the motors will start with an expenditure of only one-half the energy (electrical) that would be required if they were connected in parallel. This is because in series the motors only have one-half the line voltage for each machine and 50 amperes, whereas in parallel each motor gets the full line voltage and 50 amperes. When in series each gets one-half the line voltage, because the total voltage is equally divided between the two machines, but the "speed" of a

motor depends directly upon the electrical potential, or E.M.F., at its terminals; therefore the motors, when connected in series, will only run at one-half their normal speed, and, in order to run the cars at full speed or velocity, it becomes necessary to connect the motors in parallel, so that each motor gets the full difference of

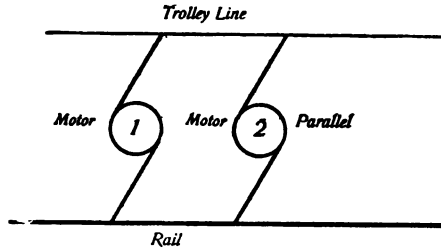


FIG. 33.—Series Motors in Parallel on Tramway Circuit.

potential, or E.M.F. For this reason a "switch" is constructed by means of which the motors are first connected in "**series**," so as to start the car at half-speed with half the expenditure of energy, and are then connected in "**parallel**," in order to run the car at full speed without additional expenditure of energy. (The counter-E.M.F. due

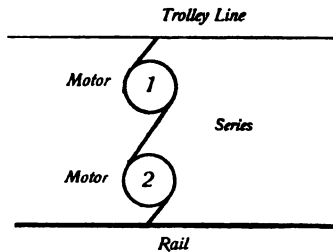


FIG. 34.—Series Motors in Series on Tramway Circuit.

to the rotation of the armatures keeps the current strength down.) Such a "switch" is called a "**series-parallel**" switch. *Figs. 33 and 34* show in a simple manner the two motors connected in "parallel" and "series" respectively. When the motors are connected as in *Fig. 33*, they run at about double the speed when connected as in *Fig. 34*. The torque or starting power is the same in each case. A

method of commuting the field magnet coils is shown in *Fig. 35*. It will be seen that there are seven different positions for the contact springs on the barrel contacts. The development of the controller, showing the various combinations of the circuits in the seven different positions, is shown in *Fig. 36*. *A.* represents the armature and brushes, *a.*, *b.*, and *c.* the divided field magnet

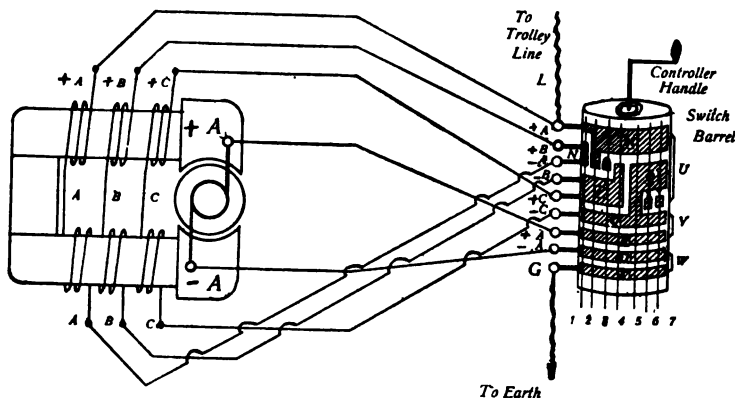


FIG. 35.—Controller Method of commuting the Field Magnet Coils.

coils, *L.* the line connection, and *G.* the earth connection in both the *Figs. 35* and *36*. Similar letters refer to similar parts in both figures.

#### 4.—“Series-parallel” Controller.

In modern electric street or railway cars the “series-parallel” switch is combined with a “field-controlling switch” and “regulating resistance.” Two of these are generally placed on each car, one at each end, so as to control the car from either end. There is also a small “reversing” switch on the controller, so as to entirely reverse the current through the motors in case of emergency; to avoid accidents, collisions, &c., and to bring the car quickly to a standstill. As before stated, the “series” motor exerts its maximum torque when at rest, for then the strength of the field and the strength of the armature current have both a maximum value. As the motor begins to move it develops a counter-E.M.F., which cuts down the current in the armature and

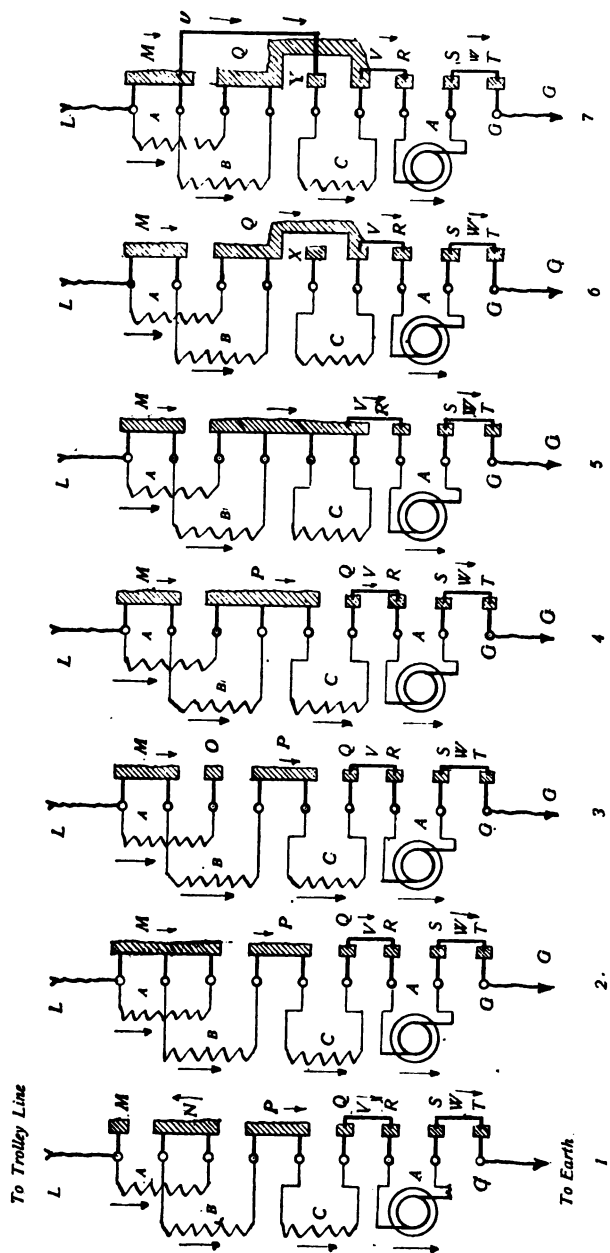


Fig. 36.—Development of Controller, showing the various Combinations of the Circuits.

in the field winding also, and the torque falls off, but resistance can be slowly cut out of its circuit, so that the maximum current, and therefore maximum torque, continues until it has reached its normal speed, when all the resistance should be cut out of the circuit. In this way we can so arrange that the motor will start from rest, under full load, with a very large torque, and continue to exert this torque till it gains full speed, the acceleration, therefore, being very rapid, which is a point of the utmost importance in traction work, where the stopping and restarting is very frequent.

The resistance to be added at starting absorbs a large amount of power when the restarting is very frequent, such as is found in the case of tramcars. This has led to an arrangement of the motors in what is known as the "series-parallel" control. The connections to the motors are made inside the "series-parallel" controller (*Fig. 37*). (Taken from Tyson Sewell's "Elements of Electrical Engineering," Crosby Lockwood.)

As before stated, one of these controllers is placed at each end of the car. Inside this controller box is a long spindle, carrying a number of stout brass or gun-metal segments, which make contact for a longer or shorter time (according to the length of each) with a corresponding number of spring contacts. The spindle is provided at its upper end with a substantial handle, and the various contacts are made by turning the handle through about 150 degrees. In this case two motors are provided, and a small resistance. The first contact joins both motors and the resistance in series on to the trolley wire, which is usually at 500 volts difference of potential to the rails. This allows the maximum current to flow, and both motors exert their full torque, but the moment they start they both generate a back E.M.F., which is added together, for the motors are in series, and so the current begins to decrease. The second contact cuts out half the resistance and keeps the current at its original value, even though there is now a back E.M.F. in the circuit, and the torque still continues at a maximum. The speed therefore increases, and the third contact cuts out all the resistance, and we have the two motors in series only (see *Figs. 32 and 34*), with the maximum current still on. The next contact changes the connections from series to parallel, and also inserts the whole of the resistance once more. This is necessary, because in changing from "series" to "parallel"

the resistance is only one-quarter what it was, and the back E.M.F. is also reduced to one-half of its former value. The maximum current is therefore still kept on the motors, though they may by this time be running at half-speed. The next contact cuts out the

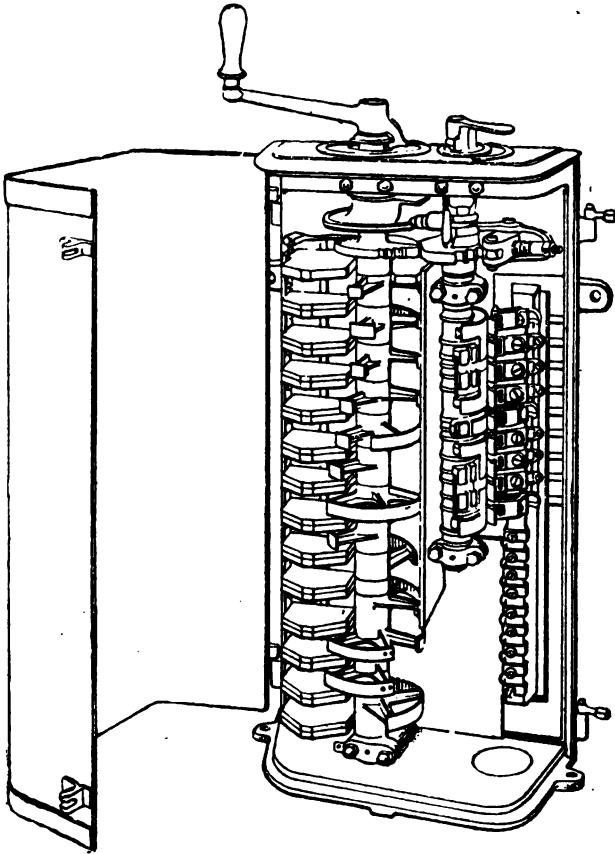


FIG. 37.—"Series-Parallel" Controller.

remaining half, and now the two motors are in "parallel" (*Figs. 32 and 33*), with no resistance in their circuit, both developing a back E.M.F., which prevents any but the current required to meet the load from passing through them. The whole operation is completed and the tramcar running at full speed from rest in a few seconds.

The connections of such a controller are given in a diagram designed by Mr. Tyson Sewell in *Fig. 38*. (Taken from Tyson Sewell, "Elements of Electrical Engineering," Crosby Lockwood.) The diagram is somewhat distorted, the segments being shown in a horizontal plane instead of one under the other, but this is so arranged that the connections may be seen more clearly. There is a small "reversing" switch, which reverses the current in the armatures of both motors, but allows the current to flow in the same direction in the field-magnet coils. A still further rotation of the controller handle cuts both motors from the line, and short-circuits

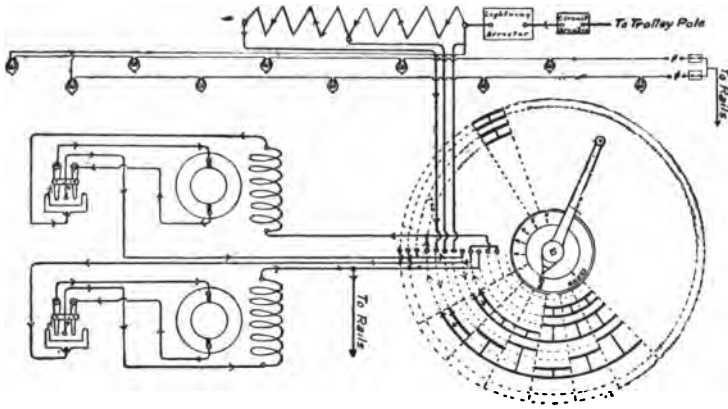


**FIG. 38.—Connections of "Series-Parallel" Controller.**

them. They then form a powerful brake. The effect of the brake, however, decreases as the speed decreases, which causes a corresponding decrease in the current, and therefore in the magnetic braking power. This is only used in cases of emergency, for there is danger of burning out the motors in so doing, owing to the large currents induced in them at a high speed, in running as generators on short circuit. The reversing switch is arranged on a second vertical spindle beside the first or main controller spindle, and the two are interlocked so that the motors cannot be reversed except when the current is off. The two controllers (one at each end of the car) are connected in parallel; that is to say, similar contacts on the two are connected together, so that when one is switched off and

locked the car can be controlled from the other. In tracing out the connections given in the diagram of the "series-parallel" controller, the row of contacts are supposed to be fixed, while the segments rotate together round the central spindle.

Another diagram illustrating a "series-parallel" controller is given in *Fig. 39*. It shows clearly the controller spindle with its contact pieces and stationary fingers. These terminals or fingers

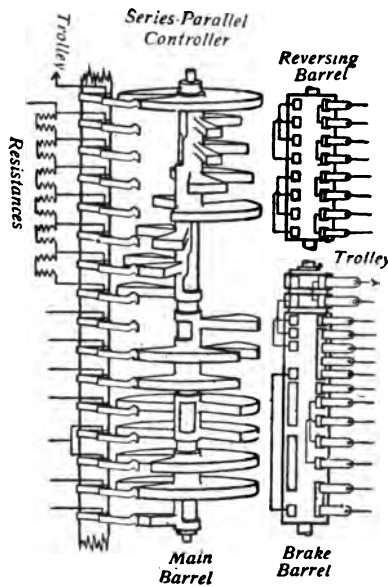


FIG. 39.—Diagram of "Series-Parallel" Controller.

are connected with other terminals or fingers placed on a connecting board, which receives wires from the trolley line, the field magnet coils, and armatures of the two motors, and the series and shunt-regulating resistances, and by varying the angular position of the cylinder any desired grouping or modification may be obtained.

The various combinations of the resistances and motors which may be effected by K type of the "series-parallel" controller,

manufactured by the British Thomson-Houston Company, are shown in *Fig. 40*, from which it will be seen that, when contact is made on the first notch, the two motors and the whole of the regulating resistances are connected in series, with the result that the starting current is under control. The resistances are then cut out step by step, and the available voltage at the terminals of the motors is gradually increased until, at contact 4, the two motors

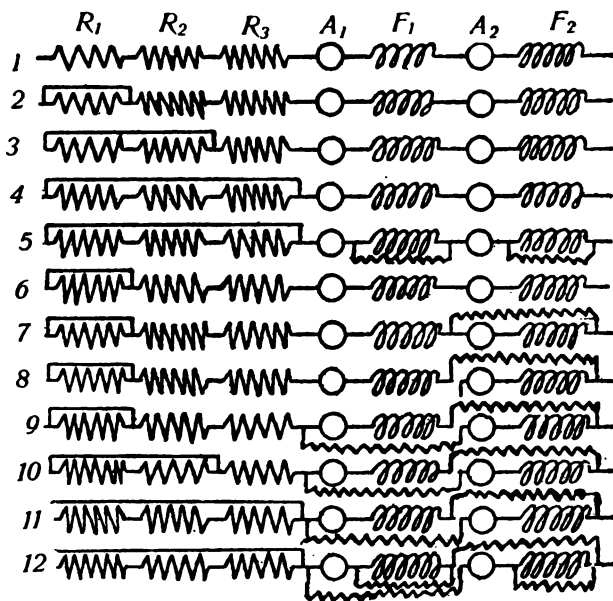


FIG. 40.—Combinations effected by the "Series-Parallel" Controller.

are simply connected in series across the 500-volt circuit. At this point, each motor receives and is operated at only half the circuit voltage; also each motor and its field magnet winding may be considered as the regulating resistance to the other; also the current produces approximately the same starting torque as would be obtained by twice the current, if the motors were connected in parallel. Notch No. 4 is termed a running point. To further increase the speed, the field magnet coils are now shunted, and as

this reduces the magnetic flux, the armatures run at a higher speed in order to produce the necessary counter or back E.M.F. To further increase the speed, the field magnet shunts are cut out; two-thirds of the regulation resistance is inserted in series again. One motor is then completely shunted, and is finally cut out of action. The two motors are then finally combined in parallel without any of the regulating resistances being in circuit. This combination occurs at contact 11, and each motor operates at 500 volts; also each motor still takes a normal current. A further increase of speed is obtained by again shunting the field magnet windings, whilst the motors are connected in parallel. This is shown in No. 12 combination.

With the "series-parallel" controller it is claimed that at starting there is a saving of 50 per cent. in current by having the motors in series compared with the current which would be required if the motors were in parallel for the speed required. The arrangement also permits a more gradual starting. In *Fig. 39*, there is also shown a reversing barrel or cylinder with its contact arrangement. The function of the reversing switch is to control the direction of motion of the car. This reversal of the direction of rotation of a "series" motor is, as previously stated, brought about by reversing the direction of the flow of current either in the armature or field magnet coils (but not in both at the same time). In practice it is customary to reverse the direction of the current flowing through the armature when it is desired to reverse the direction of motion of the car. This is effected by this "reversing cylinder," due to the requisite combination of the connections on the reversing cylinder contacts and the contact springs or fingers.

### 5.—The Electric Brake.

With electric tramcars it is of the greatest importance to be able to apply a brake quickly, especially in cases of danger and emergency. A very effective kind of braking may be attained by disconnecting the motor from the mains, and then connecting the armature brushes with each other through a resistance. When a car is provided with series motors, a reversal of the "field magnet" connections is required for getting a braking effect. Assuming the motor to be

connected as shown in *Fig. 41*, the current is flowing in the armature from *A.* to *B.*, and in the field magnet coils from *C.* to *D.* As previously stated, a back or counter-E. M. F. is produced in the armature of a motor, which, after disconnecting the motor from the mains, would tend to produce a current (generated by the rotation of the armature due to the motion of the car) leaving the armature at *A.* and entering it again at *B.* (*Figs. 42 and 43*). Hence if, for

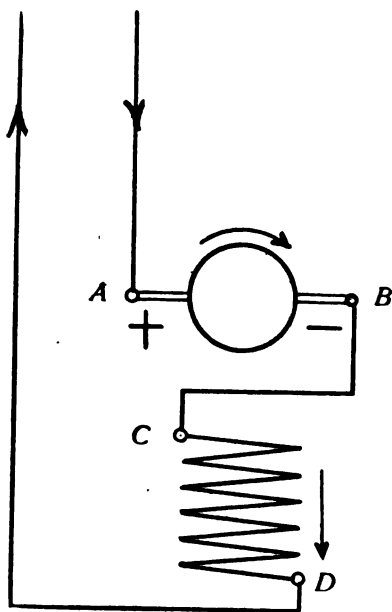


FIG. 41.—Series Motor Connections.

the purpose of braking the motor, we simply insert a resistance *R.* between *A.* and *D.*, then the current will leave the armature at *A.*, flow through the resistance *R.*, then through the field magnet coils in the direction *D.* to *C.* (*Fig. 42*), and enter the armature at *B.* Now this arrangement is wrong, because the current is flowing through the field magnet coils in an opposite direction to what it did originally. The magnetism of the motor is thus destroyed, no current is produced, and the braking effect ceases. To get a braking effect, the armature current must flow in the same direction, through

the field magnet coils, as it did in its original running position (*i.e.* from C. to D.) See *Fig. 43*. By properly arranging the connec-

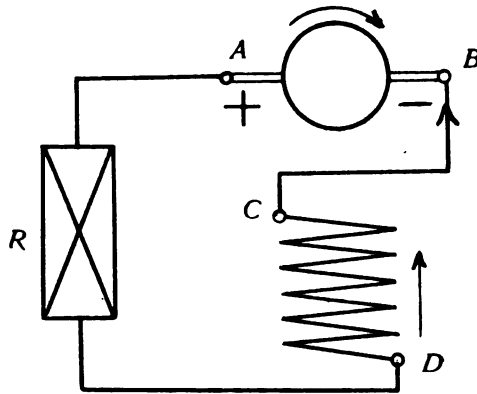


FIG. 42. —Electric Brake. Wrong Method of Connections.

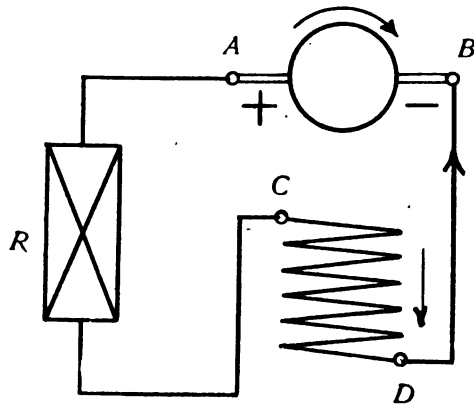


FIG. 43.—Electric Brake. Right Method of Connections.

tions, we can cause the motors to act as generators and to transform any mechanical energy, due to the momentum of the car, into electrical energy, which may be utilised (as aforesaid) to produce a

powerful braking effect. One method of producing the necessary changes in the connections is clearly shown in *Fig. 44*.

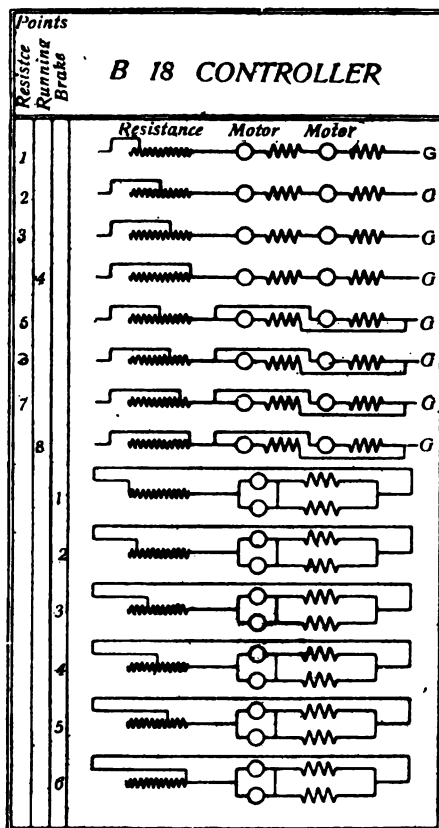


FIG. 44.—Connections to produce Braking Effect.

## 6.—Controller and Wiring Diagram of Car Connections, Brush System.

The controller connections and diagrams of the wiring connections of the system used in the Brush Standard Series-parallel Controller, with graduated rheostatic brake, are illustrated, in which *Fig. 45* shows the working at each notch of the controller, *Fig. 46*

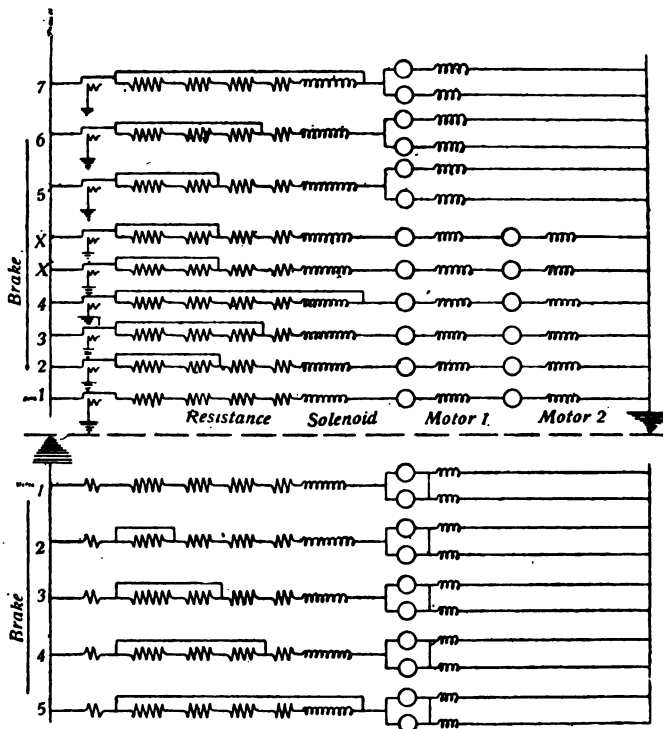


FIG. 45.—Brush System of "Series-Parallel" Controller.

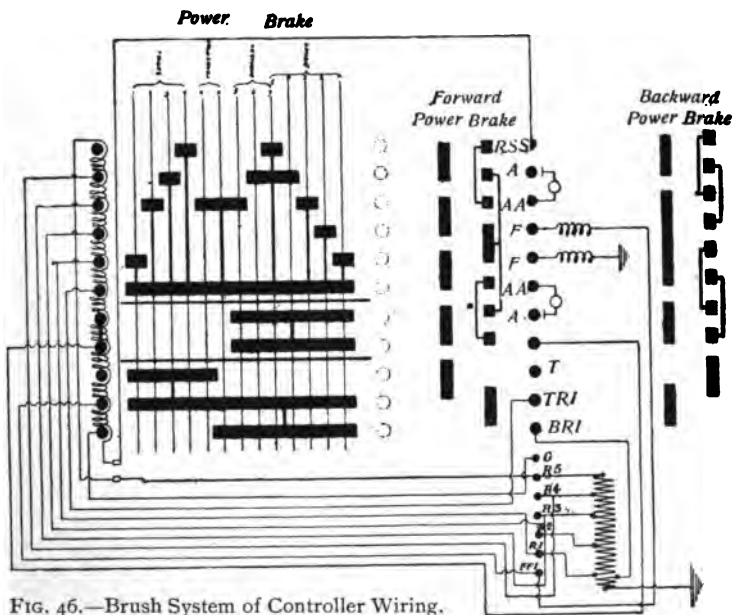
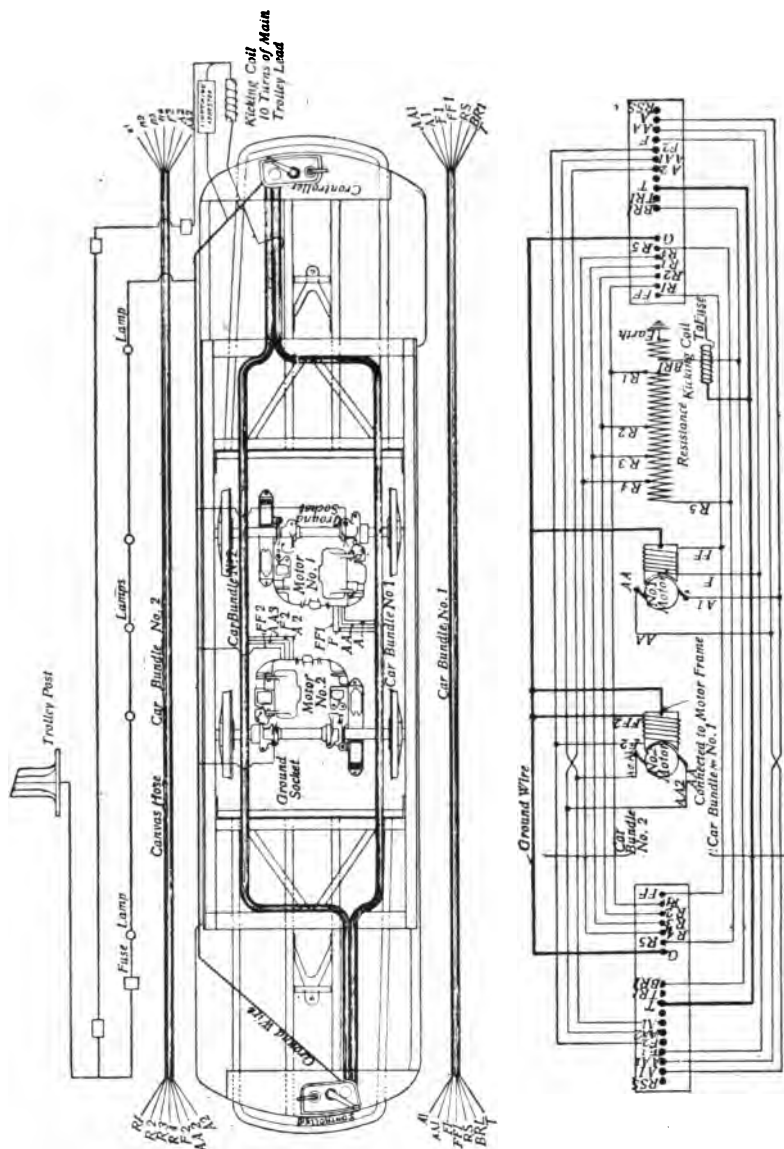


FIG. 46.—Brush System of Controller Wiring.

D.

F.



Figs. 47 and 48.—Brush System of Car Wiring.

the system of the controller wiring, and *Figs. 47 and 48* the system of car wiring.

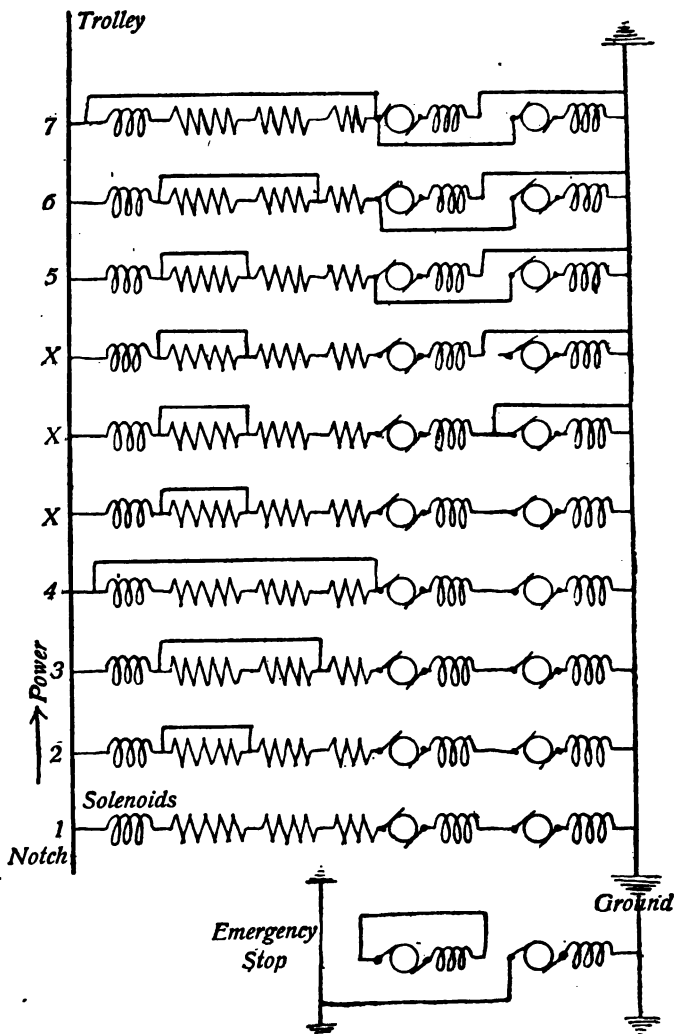


FIG. 49.—Brush Standard  $H_2$  System of Controller Connections.

### 7.—Brush Standard $H_2$ System.

In this “series-parallel” controller, fitted with an emergency brake, *Fig. 49* is a diagram of the connections of the working of the

controller at each notch, *Fig. 50* is a diagram of the controller wiring, and *Fig. 51* is a diagram of the complete wiring connections. In this type of controller, there are three resistances and one

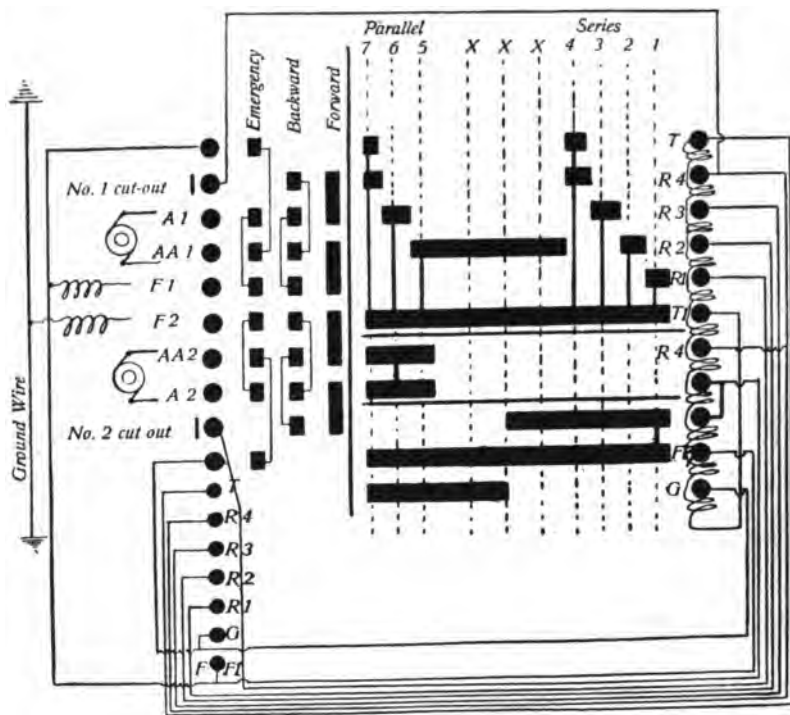


FIG. 50.—Brush H<sub>2</sub> Diagram of Controller Wiring.

running point with the motors in series, and two resistances and one running point with the motors in parallel.

#### 8.—Wiring Diagram of the British Engineering Company's Controller.

*Fig. 52* illustrates a wiring diagram of the above company's H<sub>2</sub> "series-parallel" controller. It shows the positioning of the motors very clearly.

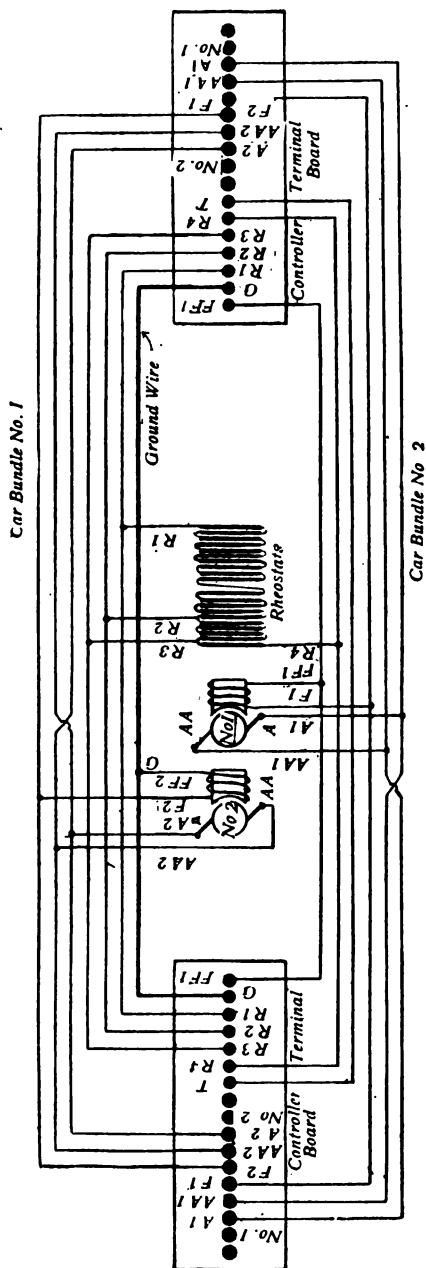


FIG. 51.—Brush H<sub>2</sub> System of Complete Wiring Connections.

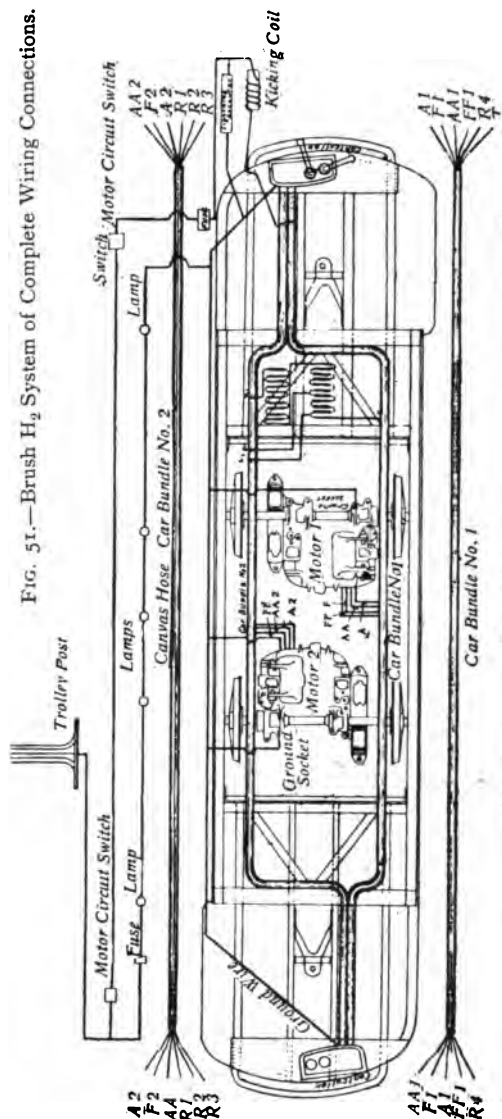
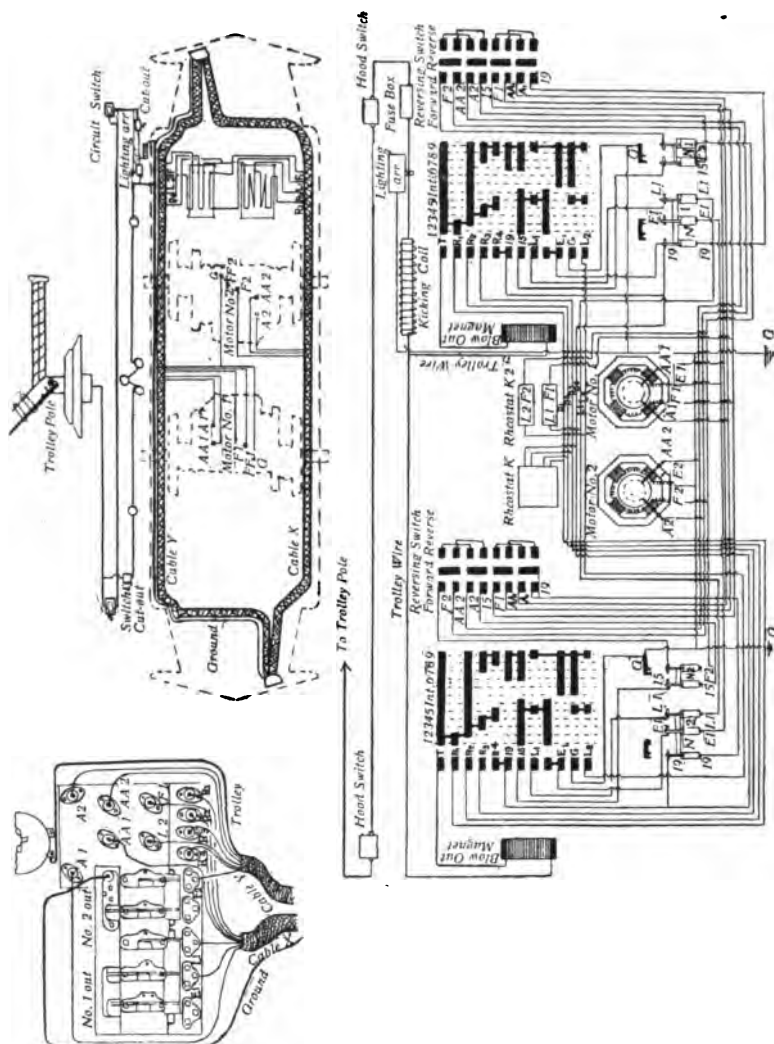


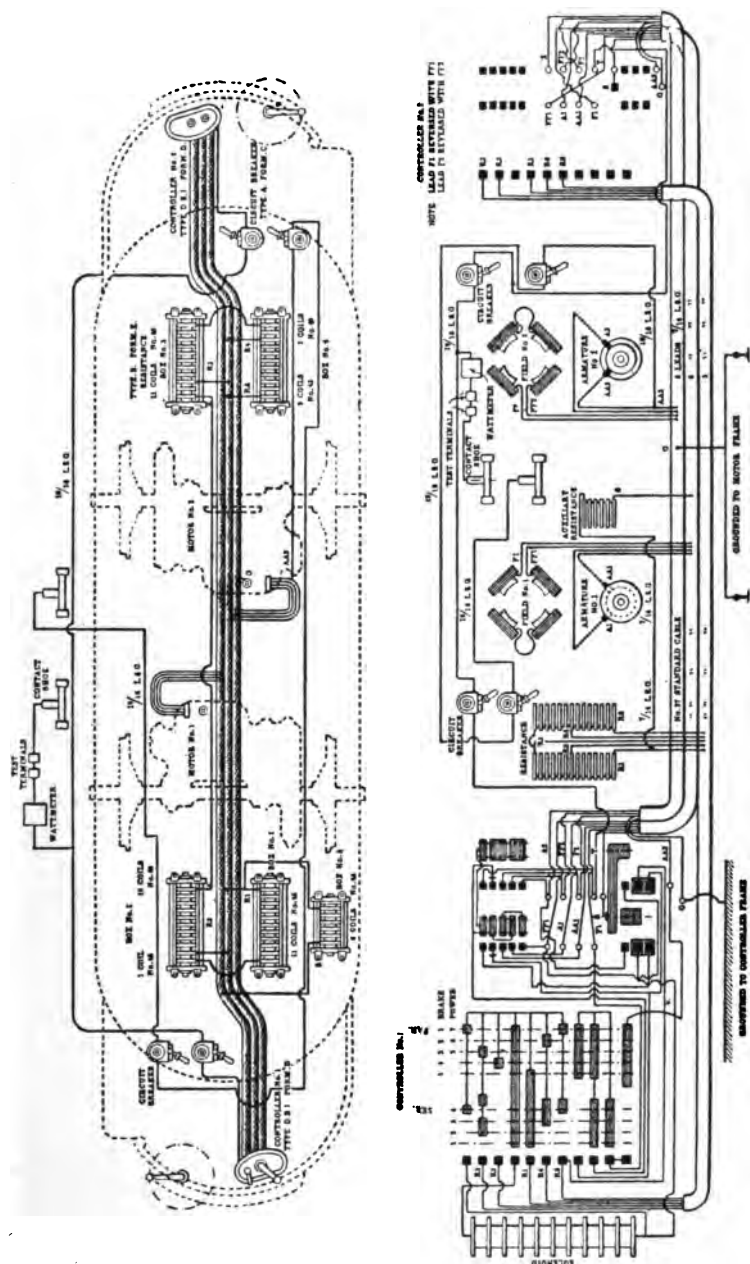
FIG. 52.—Wiring Diagram of the British Engineering Company's Controller.

## 9.—Wiring Diagrams.

Fig. 53 illustrates a wiring diagram of a  $K_2$  controller, and Fig. 54 illustrates a wiring diagram and controller connections of

FIG. 53.—Wiring Diagram of  $K_2$  Controller.

Messrs. Dick, Kerr & Co.'s controller, &c. This controller has seven power and five brake notches.



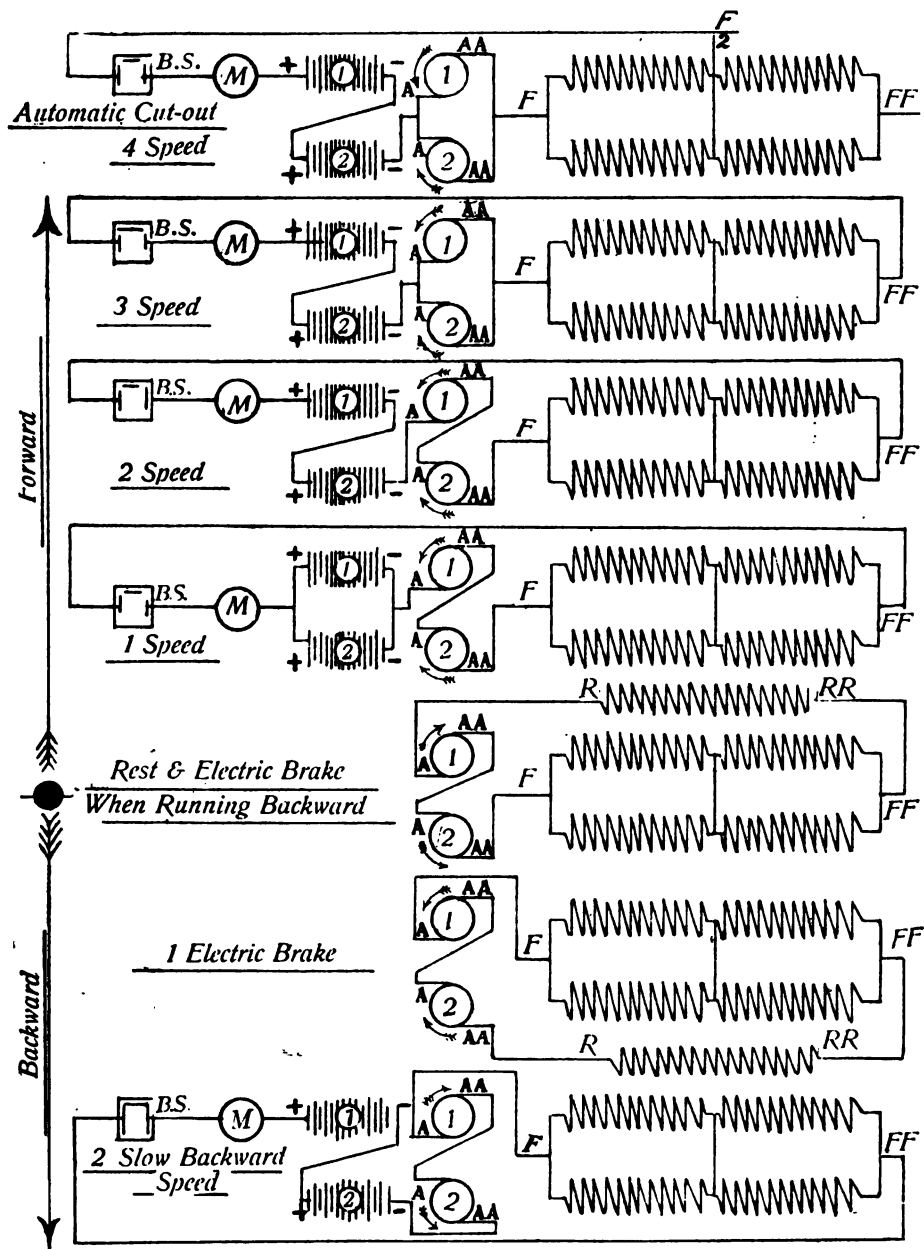


FIG. 55.—Electric Vehicle "Series-Parallel" Controller Connections.

**10.—Street Car Motors.**

The street car motors vary in size and power from about 15 to 50 horse-power each, and run at about 400 to 500 revolutions per

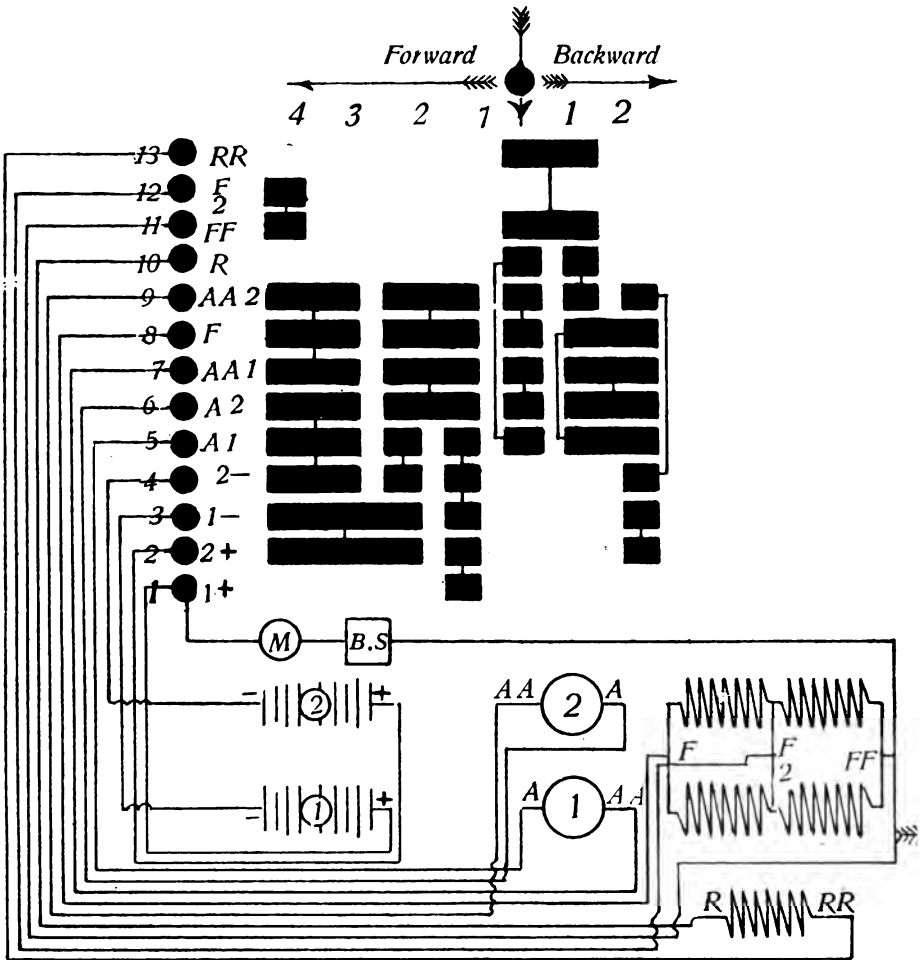


FIG. 56.—Development of the Controller.

minute, or about three or four times as fast as the car axle. The speed of the motor is reduced by gearing called "reduction gearing"; it consists of a pinion fixed on the motor shaft, which drives a larger

gear-wheel mounted upon the car axle. The motor is surrounded by a gear casing to protect the motors and gears. There is a loss of power in the use of gears, and so-called "gearless" motors have been introduced. They run at a speed of about 150 revolutions per minute, but they are not much used, for practical reasons, owing to the fact that it is mechanically difficult to suspend them, and of insulating the armature from the car axle.

## 11.—Accumulator Cars: Electric Vehicles with Storage Batteries or Accumulators.

The advantage of the storage battery system is, that each car is an independent unit; no accident can cripple a well-organised system, and the car or vehicle is not restricted to the route of an electric conductor. The disadvantages are the great weight of the battery (which is a "dead" weight) and cost of maintenance, also the lack of reserve power. Then there is the all-important question of "economy" and efficiency. For the purpose of controlling the speed of a storage battery car, the cells are grouped into two separate and distinct batteries. These batteries are connected in parallel for low speeds, and in series for high speeds. The two motors may also be connected in series or parallel. The following combinations are possible. For low speeds the batteries are placed in parallel, and feed the motors in series, for medium speeds the two batteries are connected in series and connected to the two motors in series, and for high speeds the two batteries are grouped in series and the two motors in parallel. The controllers used to effect these combinations are similar to a "series-parallel" controller. Such a method of regulating and the plan of connections for an electric vehicle is shown in *Figs. 55 and 56* (pages 56 and 57), in which *Fig. 55* shows the connections at the different speeds, and *Fig. 56* the controller development, showing the connections across the contact strips of the controller barrel. **1** and **2** are the armatures of the two motors. **A**, **AA<sub>1</sub>**, **A<sub>2</sub>**, **AA<sub>2</sub>**, are the armature connections of motors **Nos. 1** and **2** respectively. **1 +** and **2 +**, **1 -** and **2 -**, are the positive and negative terminals of the two storage batteries, **Nos. 1** and **2**. **F**. and **FF**. are the junction terminals of the field magnet coils of the two motors, **1** and **2**.  $\frac{\mathbf{F.}}{2}$  is the parallel connection of the field magnets. **R.—RR.** is the "brake resistance" coil. It is only in circuit in the backward positions, and is the electric brake resistance.

*B.S.* is an automatic brake cut out. *M.* is the main "plug" switch to entirely disconnect the electrical circuit. The "forward" and "backward" positions show the positions of the controlling handle or lever of the controller for four speeds forward and two speeds backward. The developed controller connections clearly explain the different combinations of the electrical connections for the various speeds. The round circles numbered 1 to 13 represent the 13 contact brushes which make contact with the contact strips of the rotating barrel or drum of the controller.

## SECTION IV.

### DIRECT CURRENT PLANTS, ETC.

#### COMBINED LIGHTING AND POWER SCHEMES, WITH BATTERIES, BOOSTERS, BALANCERS, &c. ; DIRECT CURRENT.

##### 1.—End Cell Switch.

In direct current working there are, under certain conditions of supply and demand, great advantages in using secondary or storage batteries in combination with the generating plant. The voltage of

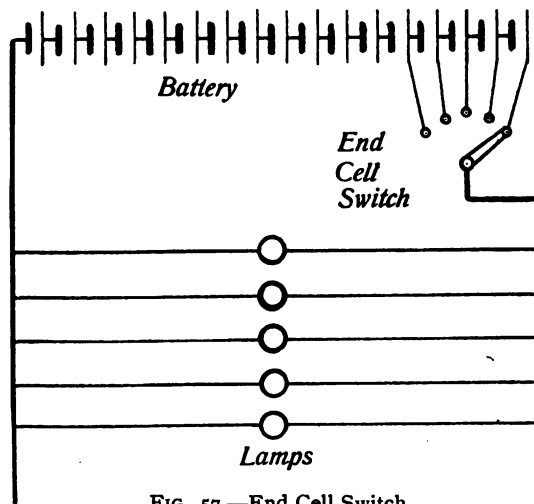


FIG. 57.—End Cell Switch.

an "accumulator" (secondary battery) varies considerably between the points of full charge and discharge voltages. It becomes necessary, therefore, to be able to vary the voltage of the "accumulator battery," so that it will work practically in unison with the generating plant and source of supply. To secure this variation of E.M.F. or pressure "end cell" switches are required. *Fig. 57* shows a "storage battery" supplying a two-wire system of distribution

in the circuit of which is placed an "end cell" switch. The normal working pressure of a cell is about 2 volts at charge, which falls to about 1.8 volts at discharge. The "end cell" switches are consequently needed to insert or take out of circuit one or more end cells, so as to regulate the voltage of the combined number of cells which form an "accumulator battery."

**2.— Combined Plant consisting of Shunt Dynamo, Storage Battery, with Charge and Discharge End Cell Switches.**

Fig. 58 shows the above combination, in which we have a "shunt-wound dynamo," with its field regulator; a "charging" end cell switch, and a "discharging" end cell switch, the whole supplying a "two-wire" system, with incandescent lamps in parallel.

**3.— Dynamo; Booster and Battery Connections.**

In practice it frequently becomes necessary to raise the voltage above the normal voltage of the dynamo during the charging of the "accumulator battery." This is done by

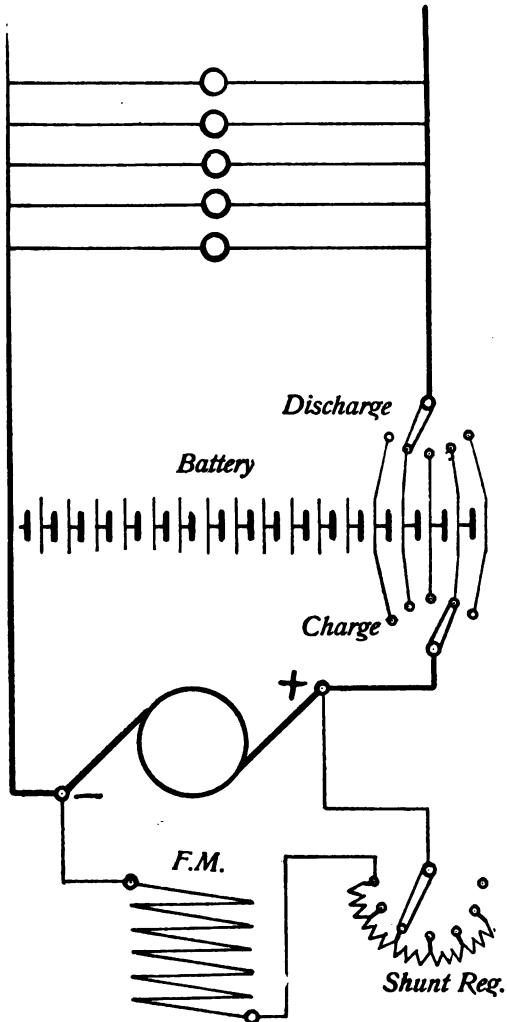


FIG. 58.—Combined Storage Battery Plant.

means of a special machine called a "booster." (A "booster" is in reality a dynamo.) The "booster" is connected in series with the dynamo by connecting its negative brush with the positive brush of the dynamo; the "battery" is connected with the negative pole of the dynamo and the positive brush of the "booster." The "voltage" can be raised to an amount equal to the voltage of the "booster" over and

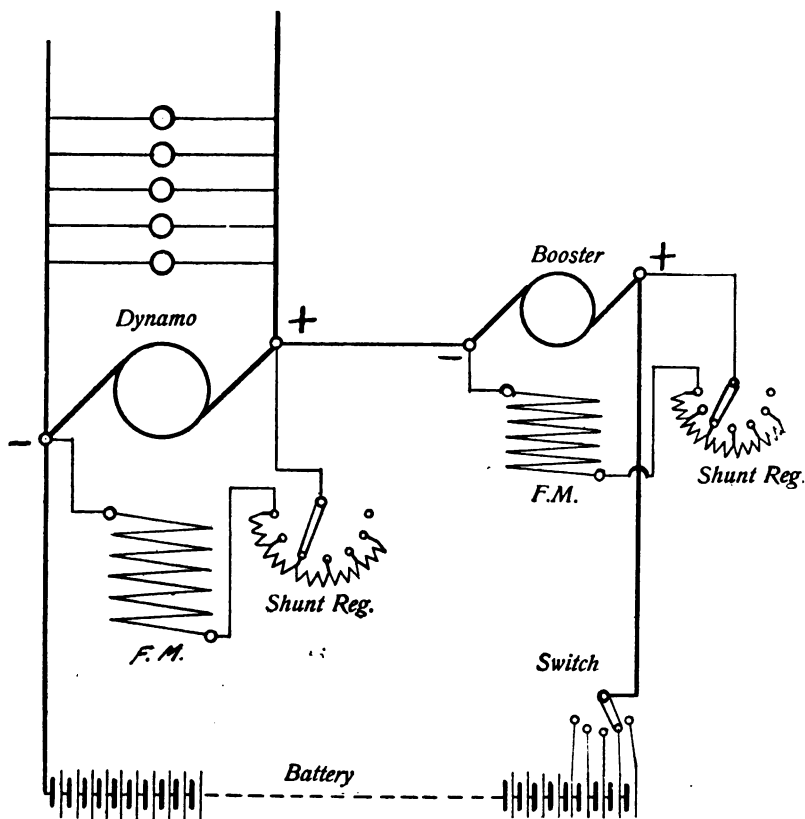


FIG. 59.—Dynamo, Booster and Battery Connections.

above the "voltage" of the supply dynamo. Its range is generally from 0 volts to about 50 volts. That is, you could raise the "voltage" of the main dynamo (100-volt machine) from 100 to 150 volts, and thus supply the terminals of the battery with any range of voltage between 100 and 150 volts. The "booster" is generally separately

excited to prevent any risk of the reversal of its polarity or field magnetism. The diagram of the connections is shown in *Fig. 59*.

#### 4.—Regulation of Pressure on the Three-wire System by means of Balancers (Equalisers).

If the number of lamps on one side of the system is very different from the number on the other side, the fall of potential on the side

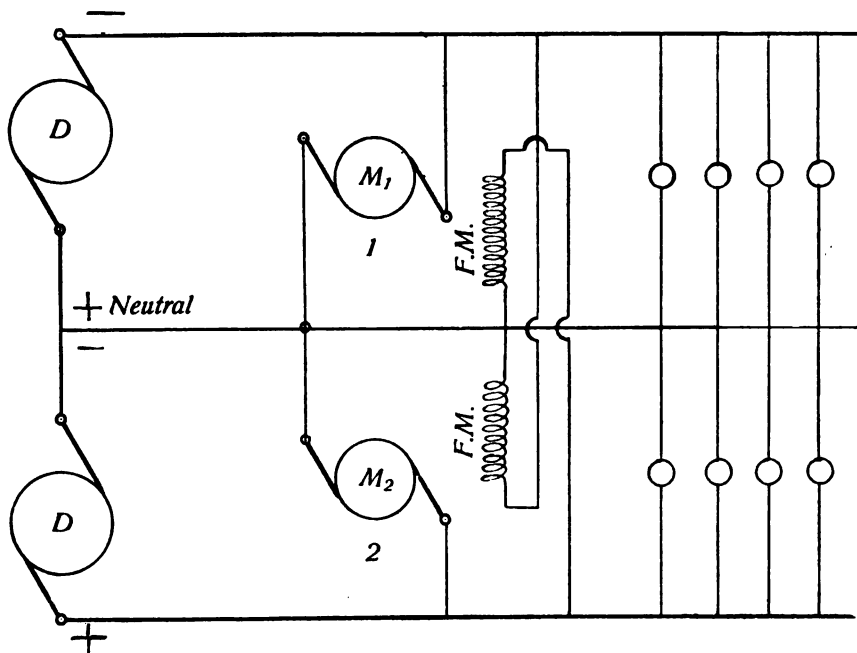


FIG. 60.—Balancer on Three-wire System.

carrying the larger number of lamps is greater than the fall of pressure on the other side. This defect has been overcome by the use of the motor generator (called balancer, equaliser, or motor compensator) in the manner shown in *Fig. 60*. Here two equal and similar motors are placed side by side, their armatures on a common shaft, and their field magnets and armatures electrically connected as follows:—

No. 1 motor ( $M_1$ ) has its field connected to the high-pressure main and the middle main, whilst its brushes are connected to the middle main and the low-pressure main.

No. 2 motor ( $M_2$ ) has its field connected to the middle and

low-pressure mains, whilst its armature is connected to the high pressure and middle mains. If the pressure between the high and middle mains is lower than the pressure between the middle and low-pressure mains, the field of No. 1 motor will be weaker than that of No. 2 motor, with the result that No. 1 armature will run faster as a motor driving No. 2 armature in a stronger field, consequently raising its back or counter-E.M.F. higher than that of the mains to which its armature is connected, so that No. 2 acts as a dynamo and

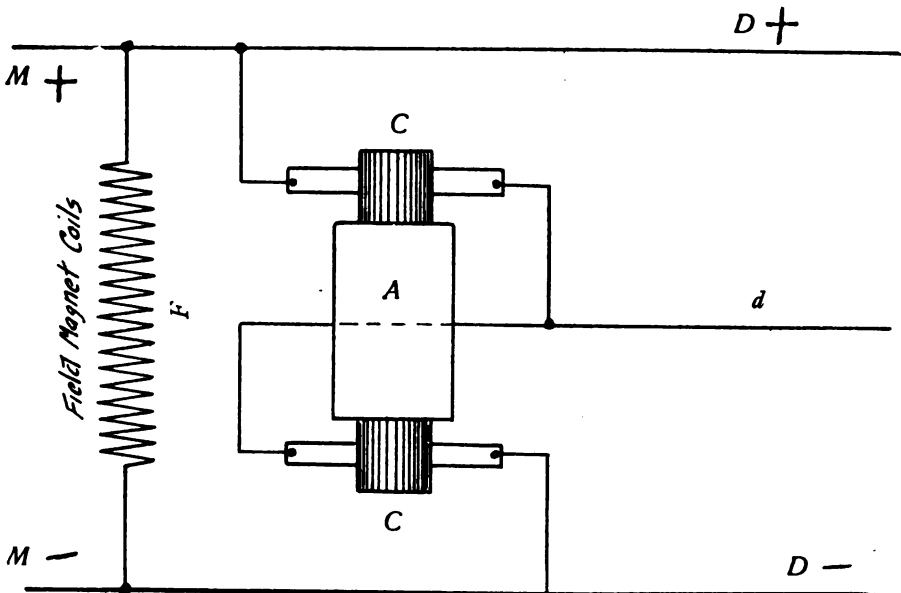


FIG. 61.—Three-wire System with Balancer.

supplies energy to the more heavily loaded side, thus automatically regulating the load, and therefore the pressure.

Fig. 61 illustrates an arrangement somewhat similar,  $C$  and  $C_1$  are the commutators of the two separate sets of coils wound on the armature  $A$ , the field  $F$  of which may be connected across the mains  $M. +$  and  $M. -$ , coming from the station bus bars. These mains are joined up with the outer distributing mains  $D. +$  and  $D. -$ , and with one brush of each commutator, the other brushes being coupled together and to the balancing distributor  $d$ . When the loads are unequal a similar equalising or balancing takes place as already described.

### 5.—Three-wire Distribution with Balancer and Batteries.

If, when the balancer is situated at the generating station, feeders instead of distributors were connected thereto, the working would not be satisfactory. In such a case a battery must be used in conjunction with the equaliser or balancer. In Fig. 62 *E.* is the

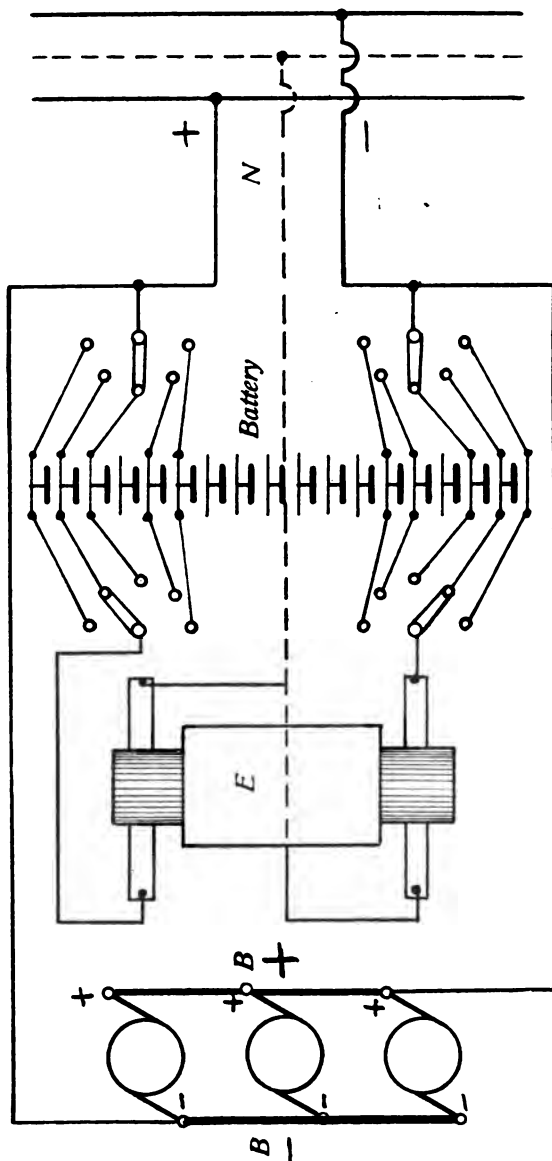


FIG. 62.—Three-wire Distribution with Balancer and Storage Battery.

"equaliser" connected through "end cell" switches with the battery. The midway points of the balancer and of the battery are connected together and with the third-wire or neutral feeder, *N*. Other "end cell" switches connect the battery with the bus bars *B. +* and *B. -*, and with the outer feeders *+* and *-*. The pressure may be regulated on either side by varying the voltage of the battery by means of these end cell switches.

#### 6. — Three-wire Direct Current System with Storage Batteries and Boosters.

The diagram of the circuit connections is shown in *Fig. 63*. *A.* are the ammeters, *D. A.* are differential ammeters, *S. P. D. T.* are single-pole double throw-switches, and, *S. P. S. T.* are single-pole single-throw switches. The end cell switches, positive and negative batteries, and positive and negative boosters are clearly illustrated in the drawing. Thirty cells on each side of the system are connected to the cell-regulating switches. Four regulating switches are installed, each having 30 contacts with a current capacity of 2,000 amperes, and are driven by a half-horse power motor, connected by worm gearing to the screw on which the contact brushes travel. An indicator is connected with these switches by means of which the last cell on the switch can be read directly from the indicator on the battery switchboard. The end cell switches are so arranged that the motors on each pair can be coupled together, and the two switches operated as one whenever the maximum discharge rate of the battery is required. Either cell-regulating switch of each pair can be connected to the main, auxiliary, and the charging bus bar; also the booster can be connected between the main and auxiliary busses. On the panels of the battery switchboard the following apparatus is mounted in duplicate: one set for each side of the three-wire system, seven knife switches, one low-reading voltmeter with 30-point switch to read the voltage of the end cells, one voltmeter with 5-point switch to read the booster and the regulating switches, one ammeter for the battery neutral, two ammeters for the end cell-regulating switches, and the two end cell switch regulators. The switchboard permits of such combinations that the battery can be discharged and charged simultaneously, the former operation at two pressures if desired, or both cell-regulating switches can be connected to the same bus for maximum discharge.

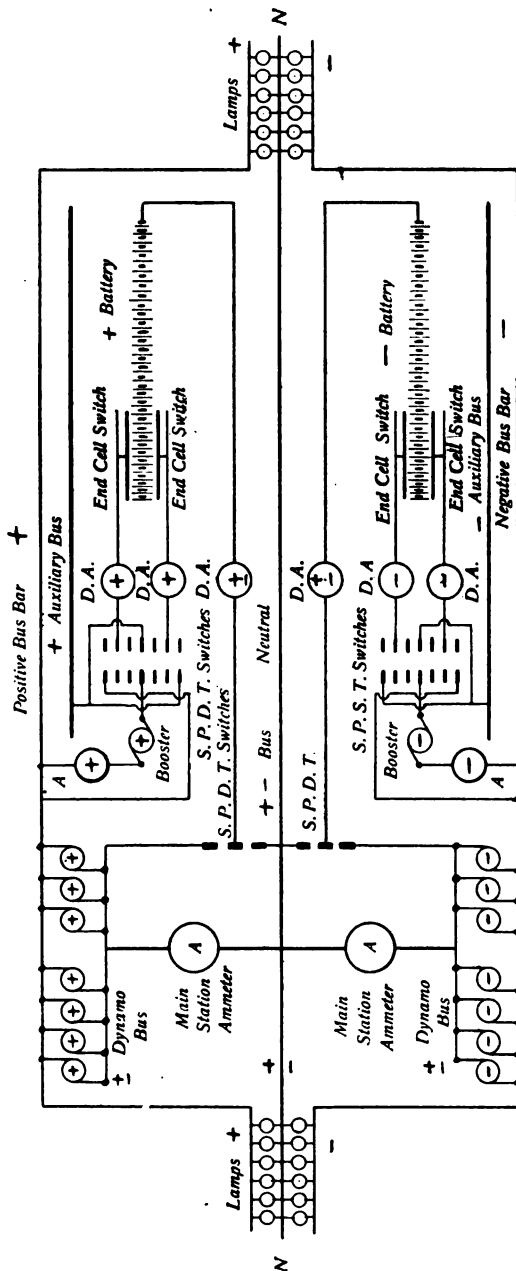


FIG. 63.—Three-wire Direct Current System with Storage Batteries and Boosters.

The battery is charged by means of motor-driven boosters, so arranged that they will maintain a constant speed under the varying voltage of the busses.

### 7.—Lighting Plant with Storage Batteries.

In *Fig. 64* is shown the switchboard connections of a combined dynamo and battery system. B. D. L. are battery dynamo lights ;

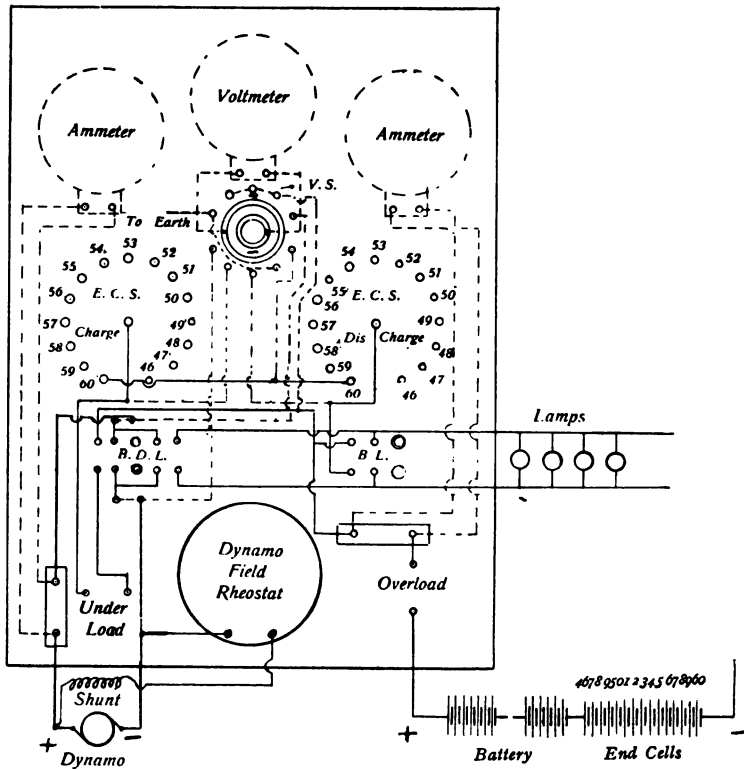


FIG. 64.—Lighting Plant with Storage Batteries.

**B. L.** are battery lights, **V. S.** are the voltmeter switches. The dynamo is shunt-wound, the voltage of which can be varied by

means of the field rheostat. There are two 15-point, round pattern end cell switches, *E. C. S.*, one in the charging and one in the discharging circuit, by means of which the whole battery (60 cells), or a less number of cells, may be charged and current taken off on

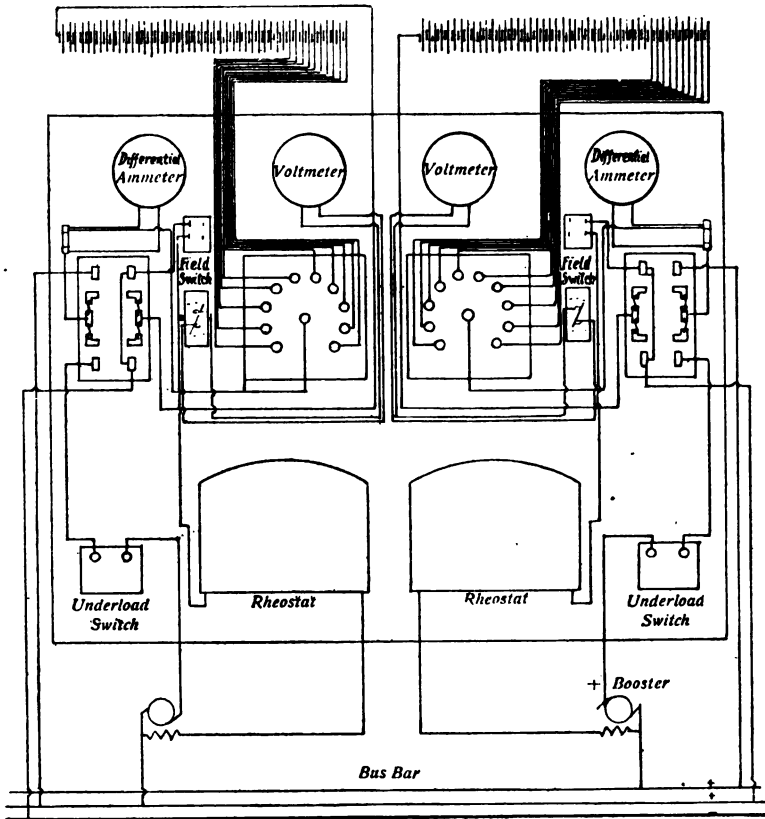


FIG. 65.—Booster and Storage Battery Plant.

the discharge switch at the normal switchboard voltage. The switchboard and connections are so designed that the dynamo may be run to charge the battery or to furnish lights direct, or both of these operations may be done at the same time. The battery

may be used in parallel with the dynamos, or the battery may be used alone.

### 8.—Booster and Storage Battery Plant.

The diagram of connections is shown in *Fig. 65*. From the main board three feeders run to the storage battery switchboard. A double-throw switch is provided, by which the batteries can be switched to discharge into the lighting system, or connected to the dynamos in series with the boosters. The switchboard also comprises a differential ammeter and a voltmeter, a ten-point end cell switch, a booster rheostat, and an underload switch, which breaks current should the batteries tend to come back on the dynamos. These instruments are duplicated on each leg of the system. There is a double-pole, double-throw switch which cuts out the boosters. The underload switch is very ingenious. It consists of an iron core pivoted at each end to a horizontal brass support, which is fastened to a vertical piece of slate. At the ends of the core and at right angles thereto are secured heavy iron pole pieces. The supports extend beyond the core, and carry an iron armature, which, when the switch is closed, completes the magnetic circuit. Around the core are wound a few turns of heavy wire, with the ends bent in such a way that when the switch is closed they dip into mercury cups, completing the circuit from one main through the booster and battery back to the neutral. Should the booster voltage fail from a broken belt or other cause, the voltage of the charging circuit would drop to that of the dynamo, and the consequent reduction in current would allow gravity to act on the heavy pole pieces of the switch, causing the latter to fall and open the circuit.

### 9.—Three-wire, Booster, Battery and Feeder Connections.

*Fig. 66* gives a diagram of the connections of the above. This diagram shows very clearly the end-cell switches. Twenty of the end cells on each side of the system are used for regulating. Each of these cells is separately connected to a contact on the regulating switches, which carry movable contacts operated by a screw. The

potential is raised or lowered by cutting in or cutting out regulating cells. Two regulating switches are connected in multiple on both

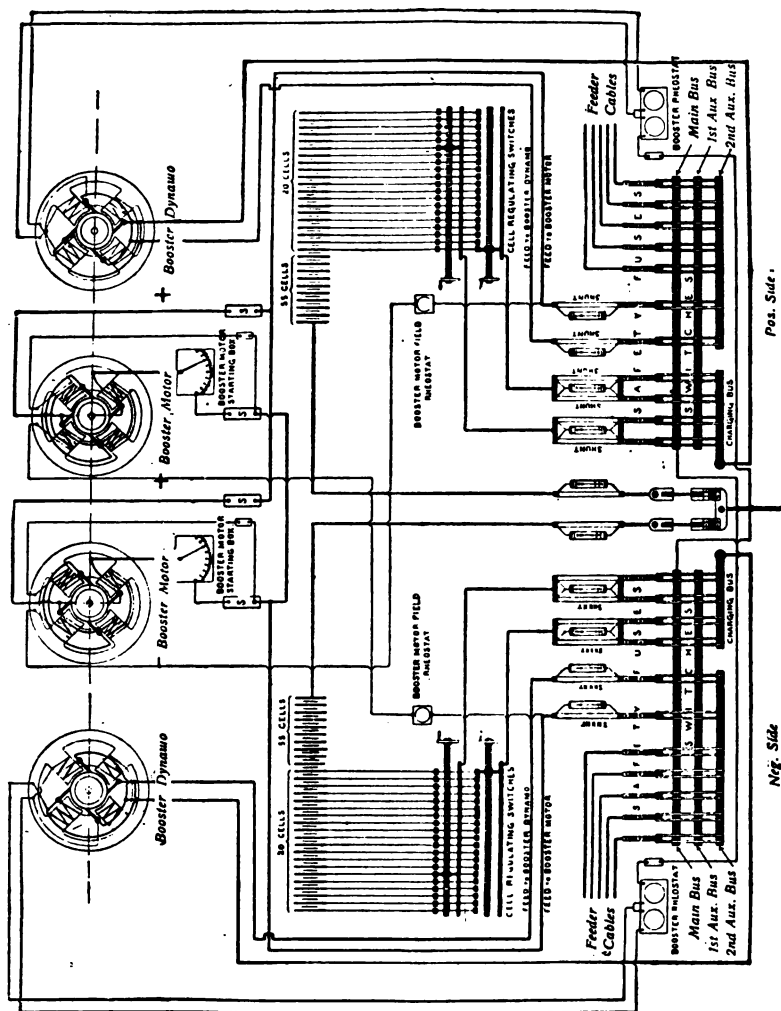


FIG. 66.—Three-wire, Booster, Battery and Feeder Connections.

the positive and negative sides to permit of a discharge at two potentials, or to enable the battery to be charged and discharged simultaneously. The booster is used to raise the E.M.F. of the



charging current from the potential of the current supplied to the installation to that required for charging the battery. The booster can be used also to raise the E.M.F. of discharge for feeding some distant point of the system at a higher potential than would be

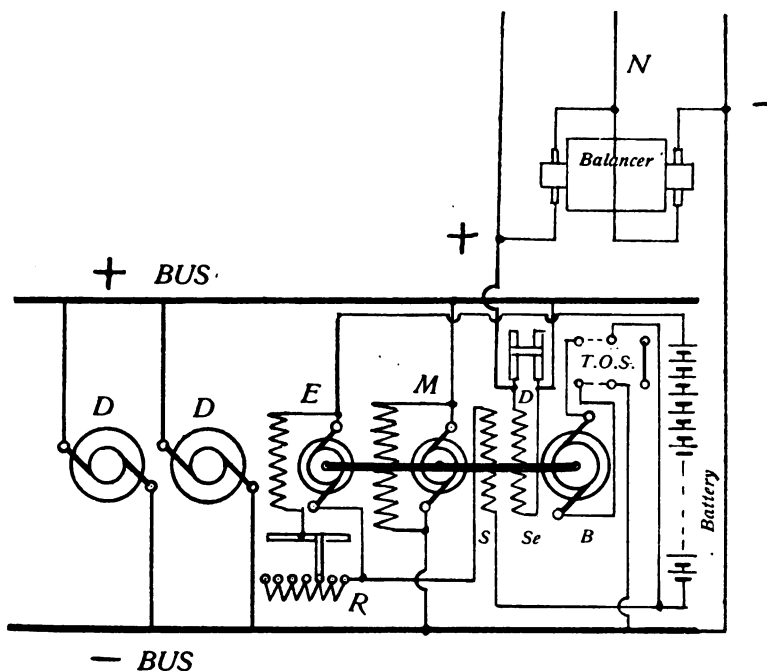


FIG. 67.—Reversible Booster arranged for Lighting Work.

normally required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two compound wound motors.

#### 10.—Reversible Booster arranged for Lighting Work.

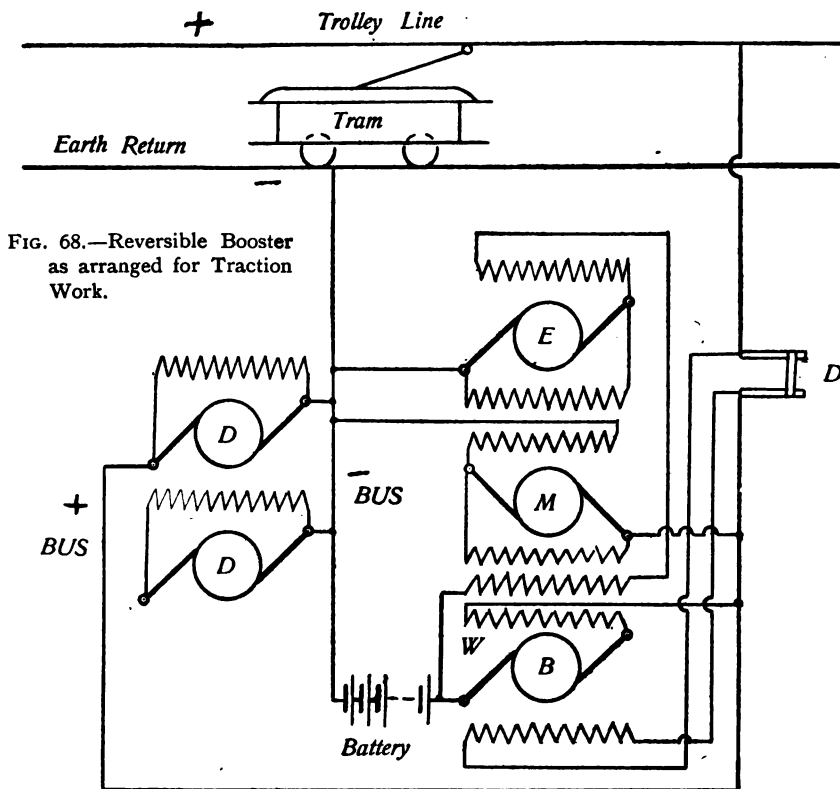
A "reversible booster" not only boosts up the supply voltage to enable a battery to become charged, but also boosts up the

battery pressure when it is discharging, setting itself automatically to perform either function, according to the requirements. The "Highfield" reversible booster performs the above. In *Fig. 67* *B.* + and *B.* - are the bus bars, and *D.* and *D.* the dynamos. The boosting arrangement consists of three machines: a motor, *M.*, booster, *B.*, and "opposer" or booster exciter, *E.* The booster shunt field coil *S.* is connected in series with *E.*, which supplies the exciting current for the former, and the two are joined up to the ends of the battery. The number of cells in the battery must be such that at the normal E.M.F. per cell its total E.M.F. shall be equal to that between the bus bars. The exciter *E.* is shunt-wound, and a rheostat, *R.*, enables its excitation to be adjusted. The motor *M.* is also shunt-wound, and is connected across the bus bars. The "booster" armature is connected in series with the battery. A double-pole throw-over switch, *T.O.S.*, enables the booster to be cut out. In addition to the shunt winding, the booster has also a series winding, *Se.*, through which passes a fraction of the main current flowing into the + feeder, this fraction being determined by the position of the slide on the rheostat *D.* The winding *Se.* gives a slight boost in the discharge direction, but this is only appreciable when an extra heavy current is flowing to the feeder. Thus its purpose is to assist the discharge when the load becomes very great. The motor drives the booster and exciter at a constant speed, and the latter gives a constant pressure equal to the normal line voltage. As long as the battery and exciter voltages are equal there will be no current in *S.*, and consequently no boost, but directly the battery pressure falls below that of the exciter the latter acts as a generator, supplying current through *S.* to the battery and causing the booster to give a pressure exactly equal to the difference between the exciter and battery pressures. The current supplied in this way by the exciter to the battery never exceeds about five amperes, and thus plays no appreciable part in the charging of the battery.

When the battery pressure rises above that of the exciter a current from the battery will flow through the exciting coil *S.* of the booster, reversing its polarity, and also through the exciter *E.*, which will now run as a motor. The boost of *B.* will then again be equal to the difference between the exciter and battery pressures, but in the opposite direction.

### II.—Reversible Booster as arranged for Traction Work.

The Highfield reversible booster is also suitable for traction work. Fig. 68 shows the arrangement. *D. D.* are the dynamos, *B. B.* the bus bars, *M.* the motor, *E.* the exciter, *B.* the booster, and *D.* a rheostat. *E.* is compound wound, and *M.* is differentially wound, the speed of the latter being thereby kept more constant. The booster



*B.* also has an additional winding, *W.*, in series with the armature, the function of this being to compensate for armature reactions. The negative pole of the system is connected to the rails (*i.e.* to earth), this being the usual practice, as the effect of electrolysis is thereby minimised. The field magnets of a reversible booster must be laminated, in order that when the magnetising current in the shunt winding is reversed the change of polarity may take place rapidly.

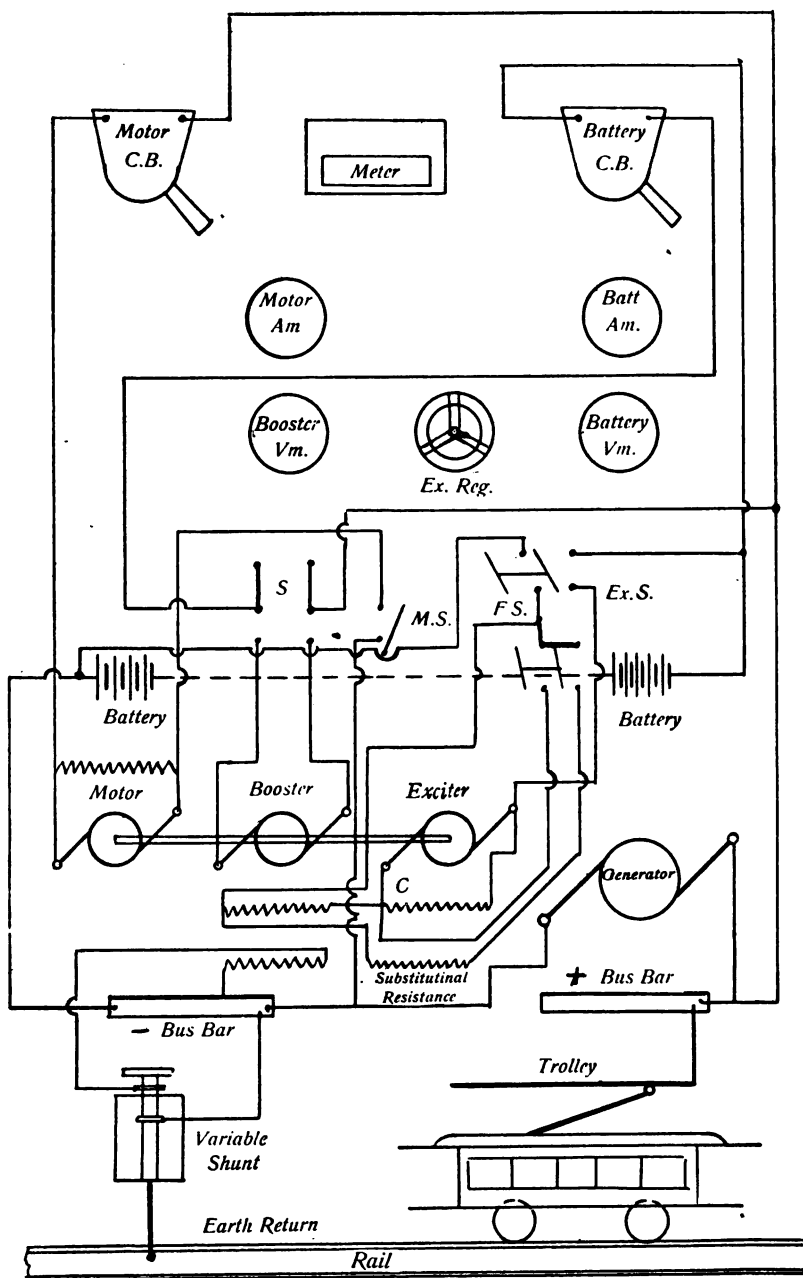


FIG. 69.—Reversible Booster as arranged for Traction Work.

A somewhat more complete combination of the Highfield reversible booster as arranged for traction work is shown in *Fig. 69*. Some of the minor and less important circuit connections are left out, however, so as to keep the diagram as clear as possible. Still at the same time it illustrates the more important connections. This machine is of special construction and design for working in series with a storage battery, keeping a fluctuating load, as a "tramway" one, with a practically constant potential, and also the load on the generator the same. The "booster" armature is always in series with the "battery," running when the "generator" is running, and sometimes when the "battery" alone is working the line. The diagram shows the "booster" driven by a "motor." The "booster" has laminated fields, excited by a fine wire coil, *C*. (the exciter coil), of such proportional resistance that the armature pressure at a constant speed is similar to the pressure across the "exciter" coil ends. Any "drop" is corrected by a "series" winding. The armature leads are connected to the negative terminal of the battery by "exciter" coil *C*. So long as the "exciter" and "battery" pressures are equal, no current will flow in *C*.; hence the "booster" will give no pressure. Should the battery volts rise, a current will flow in *C*. proportional to the difference of the "battery" and "exciter" pressure (which exciter will be motored). The "booster armature" will then give a pressure equal to the rise of battery pressure. Should the "battery" pressure drop, the "booster" will give out a pressure equal to the drop, but will have its poles reversed, the exciter now running as a generator and giving a current to the battery. Generally the "exciter" runs as a "motor" when charging, and as a "generator" when discharging. The "booster" fields being "laminated," the reversal of the "polarity" is rapidly made. To increase the pressure as the load on the line increases, part of the feeder current is shunted round a coil on the "booster" fields, in such a direction as to "help" the "discharge" or "oppose" the "charge."

## SECTION V.

### ALTERNATING AND POLYPHASE CURRENTS.

#### ALTERNATING AND POLYPHASE CURRENTS, POWER TRANSMISSION, SYNCHRONISING, &c.

##### 1.—“Synchroniser.”

In the “paralleling” of **alternators** the machines have to be “**synchronised.**” This is done by means of a “**synchroniser,**” which may consist of a small transformer, wound with two primaries

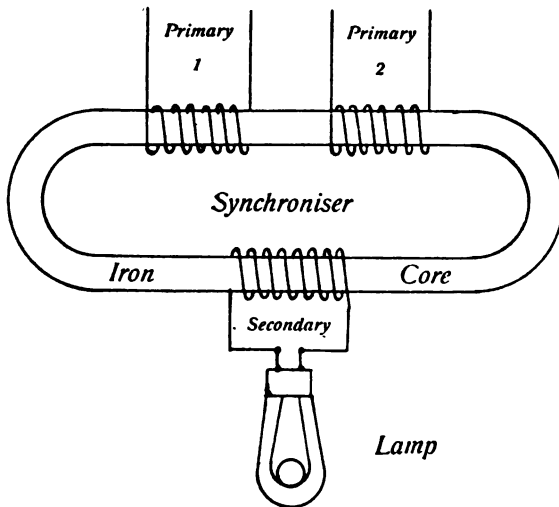


FIG. 70.—“Synchroniser.”

and one secondary. The principle of action depends upon the “**mutual induction**” between the primary and secondary windings (Faraday’s induction of currents). A “**synchroniser**” is represented in *Fig. 70*. One primary is connected to the bus bars of the alternating current system, the other primary is connected to the new machine to be switched in, and the secondary has a lamp in

series, as shown. When the speed and voltage of the two machines are right, if the voltages are not in phase, the effect will be a blinking of the lamp on the synchroniser. By altering the speed the new machine is brought into "synchronism," which is shown by the lamp burning or glowing bright and steady. The machine is then quickly switched in.

## 2.—Paralleling of Alternators.

In using alternators for lighting circuits, it is necessary to run them in parallel with each other, and before this can be done they must be "synchronised"; *i.e.*, they must have the **same voltage**,

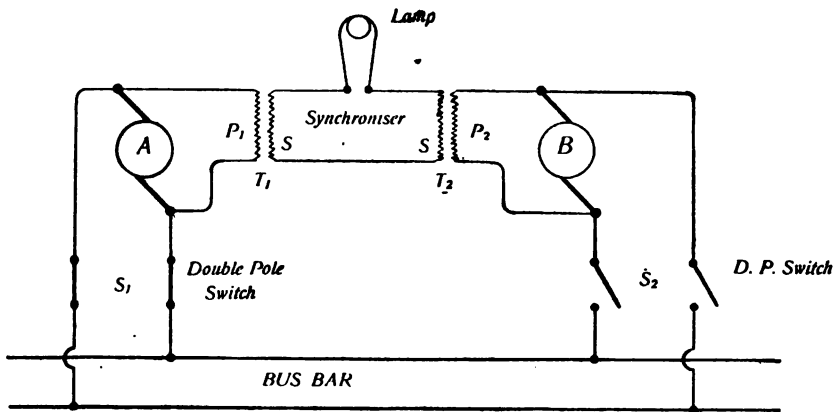


FIG. 71.—"Synchronising" Alternators.

**same frequency**, and be exactly in **unison**, **step**, or **phase**; *i.e.*, the positive and negative alternations of each machine must occur exactly at the same instant. The method of using a "synchroniser" in connection with the alternators is shown in *Fig. 71*. The alternator *A*., which is already feeding the main circuit, is shown connected up by means of a double pole switch to the "omnibus bars" on the switchboard. This alternator is likewise connected to the primary ( $P_1$ ) coil of a small transformer,  $T_1$  (the "synchroniser" is connected as a "shunt" to the main circuit), the secondary coil being connected in series with a lamp and the secondary coil of another transformer,  $T_2$ , whose primary coil,  $P_2$ , is connected up to a second alternator, *B*., which it is now desired to connect up to the "omnibus bar." The E.M.F. generated at any instant in the two secondary coils due to

the mutual reaction of the primary coils may be acting either in unison or opposition. In the former case, the light given out will be

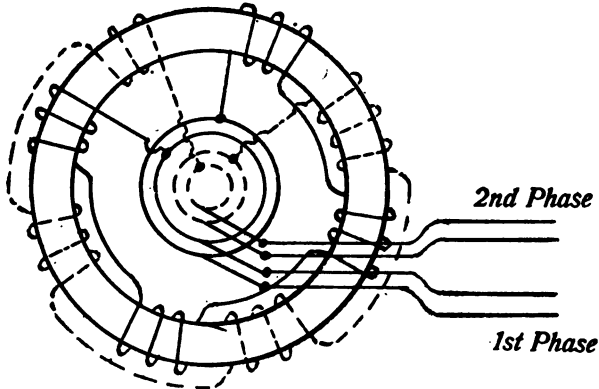


FIG. 72.—Method of Collecting a Current from a Two-phase Generator.

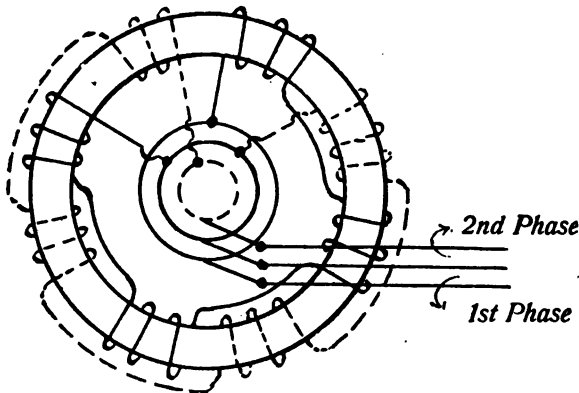


FIG. 73.—Another Method of Collecting a Current from a Two-phase Generator.

a bright light; in the latter case, a flickering effect will be observed. The machine is switched in when the light is bright and steady.

### 3.—Polyphase Currents.

In *Figs. 72 and 73* are shown two methods of collecting the current from two-phase generators. *Fig. 72* illustrates a two-phase circuit

in which the currents are collected from four collecting or slip rings; *Fig. 73* illustrates a two-phase circuit in which the currents are collected from three collecting or slip rings.

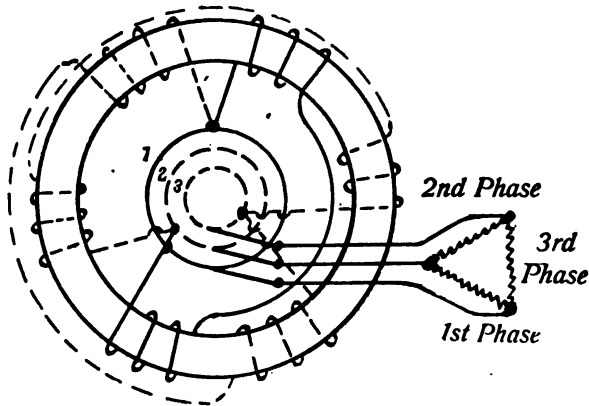


FIG. 74.—"Triangular" or "Mesh" Connection of a Three-phase Circuit.

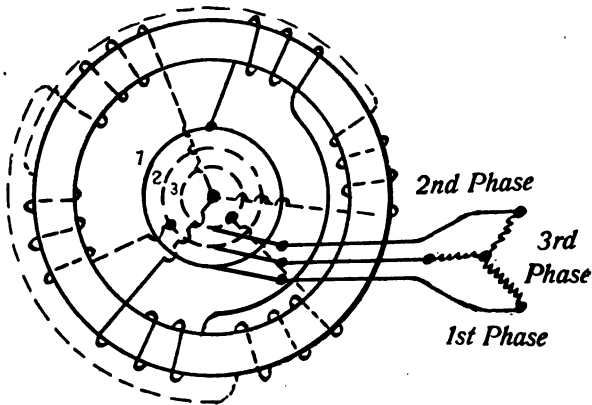


FIG. 75.—"Star" Connection of a Three-phase Circuit.

*Figs. 74 and 75* are examples of three-phase circuits. In each case there are three collecting or slip rings. In *Fig. 74* it will be noticed that the six free ends of the coils of the generator are connected

two ends on each slip ring, the external circuit connection forming what is known as the “**triangular**” or “**mesh**” connection. The first winding on the generator is connected between slip rings 1 and 2, the second between slip rings 2 and 3, and the third between rings 3 and 1.

In *Fig. 75*, the beginning of each winding is connected to one of the collecting rings, and the other free ends are brought to a common

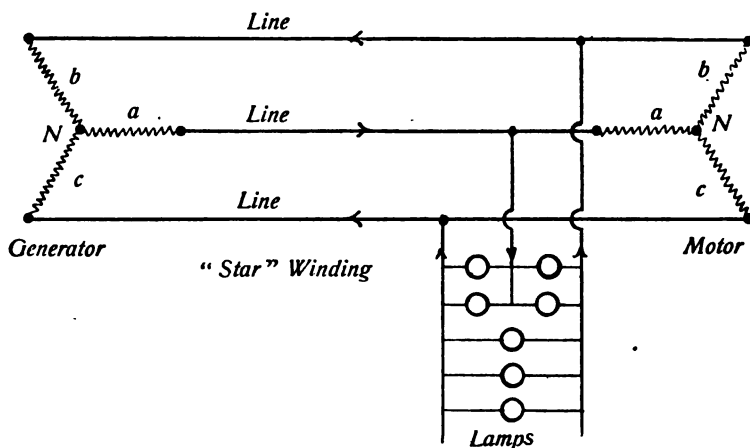


FIG. 76.—“Star” Method of Polyphase Transmission of Power.

junction, this method of winding forming what is known as the “**star**” connection.

#### 4.—Polyphase Transmission of Power.

The methods and connections for the transmission of power from the generators, as connected in *Figs. 74* and *75* to motors, &c., are illustrated in *Figs. 76* and *77*. In *Fig. 76* this represents the “**star**” method of winding and connections. *Fig. 77* represents the “**mesh**” grouping or method of connecting. In *Fig. 76* *N.* is the common junction or neutral, the other free ends being connected to the lines and carried to the motor. The figure shows the “**armature**” of the “**generator**” and the “**field coils**” of the “**motor**” connected by three main leads. When the current in *A.* is at its maximum,

D.

G

then the currents in *B.* and *C.* coils are equal, and each is one half the value of *A.*, under which circumstances *B.* and *C.* leads, act as a return for *A.*. The three sets of coils in the "armature" of the generator and the motor field are sometimes joined in series, and the three junctions connected to the three main leads. This gives us what is known as the "**mesh**" grouping or method of winding (*Fig. 77*). It will be seen that the "mesh" winding approximates somewhat to a parallel method of winding when considered with respect to the external circuit, with the result that the "pressure" between the mains is less than the equivalent "**star**" grouping, the currents being correspondingly heavier. For transmission of power to great distances, where "**low**" current strength and correspondingly "**high**" pressure in the mains is essential, the "**star**"

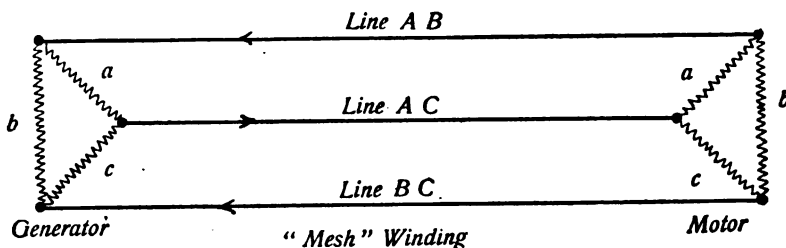


FIG. 77.—"Mesh" Method of Polyphase Transmission of Power.

grouping is preferable. To obtain a given pressure in the mains with a "**mesh**" grouping requires about 73 per cent. greater length of conductor in the armature than with the "**star**" grouping. There is the advantage in the "mesh" grouping that, although one set of windings in the **generator** or "**rotor**" may break down, the machines will continue to run as two-phase machines, whereas with "**star**" windings the machines would become simple **single-phase** and would not be self-starting. The great advantage of "polyphase motors" is that they are self-starting, do not need to run in "synchronism" (asynchronous), require no slip rings or brushes; and polyphase machines in general are specially suitable for the transmission of power to considerable distances, where a "high pressure on the line is essential" to economy as regards weight of copper.

## TRANSMISSION OF MULTIPHASE CURRENTS.

## 5.—Two-phase Transmission with Four Wires.

Power may be transmitted by polyphase current in a variety of methods as regards the number of mains, such, for example, as power transmitted between a generator and a motor. Two currents produced in a two-phase generator may be separately conducted by means of

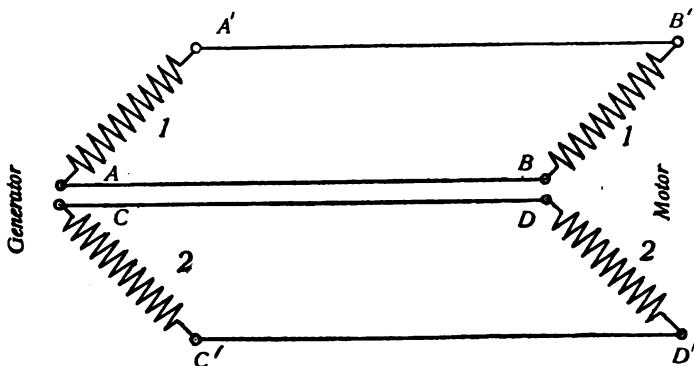


FIG. 78.—Two-phase Transmission with Four Wires

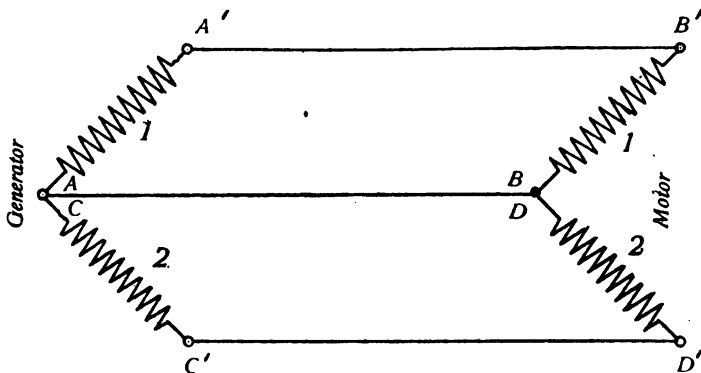


FIG. 79.—Two-phase Transmission with Three Wires.

two pairs of wires to a two-phase motor. In this case, four mains are required, as shown in *Fig. 78*. The windings 1 and 2 indicate the first and second phase windings on the generator and motor.

## 6.—Two-phase Transmission with Three Wires.

We can, however, combine two of the mains into one main, say *A.B.* and *C.D.* In this arrangement (see *Fig. 79*) each phase has

G 2

one main for itself, but the middle main is common to both phases. This middle main is the common or return main for the two currents flowing in the two outer mains. The sectional area of the middle wire must be about  $1\frac{1}{2}$  times that of either outside wire, because the resultant value of these two component currents is about 1.41 times the value of each taken separately.

#### 7.—Three-phase Transmission with Six Wires.

With three-phase transmission we may lead six wires from the generator to the motor. The three-phase windings are indicated by 1, 2, and 3 in *Fig. 80*.

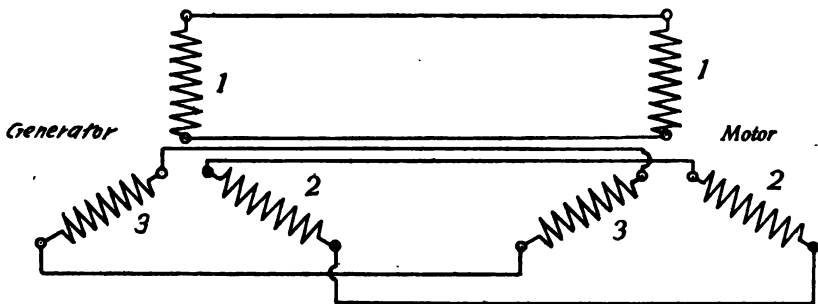


FIG. 80.—Three-phase Transmission with Six Wires.

#### 8.—Three-phase Transmission : “Star” connected with Four Mains.

We can combine the returns, connecting the inner ends of the generator and motor returns together to form one common return. We thus get three single leads and one common return, as shown in *Fig. 81*. When the phase voltage is 100, the voltage between the outer terminals is 173, and between any outer and return is 100 volts.

#### 9.—Three-phase Transmission : “Star” connected with Three Wires.

In *Fig. 82* is shown the arrangement with three wires only, dispensing with the common return. The common return wire is not necessary when the generator is only supplying power for motors. Between any two of these mains the voltage is equal.

### 10.—Three-phase Transmission : Mesh Connection with Three Wires.

Fig. 77 illustrates the “mesh” or “delta” connection. The voltage between the outer mains is equal to the phase voltage. Assuming that in these several cases the “phase voltage” is 100 and the “phase” current is 100 amperes, we find in the

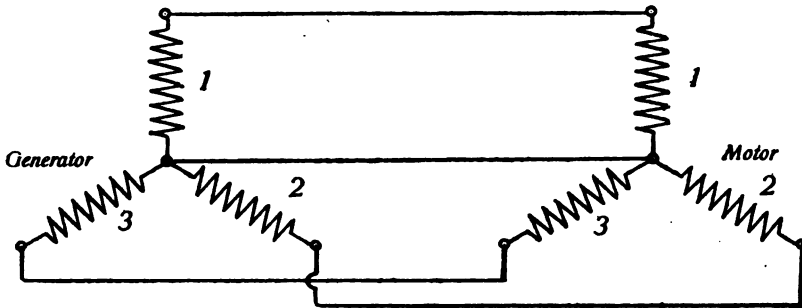


FIG. 81.—Three-phase Transmission “Star” connected with Four Wires.

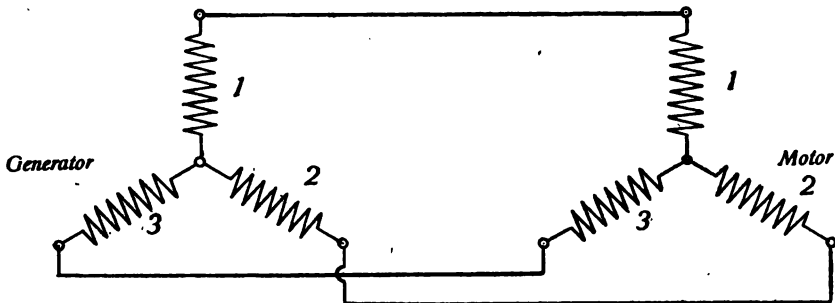


FIG. 82.—Three-phase Transmission “Star” connected with Three Wires.

“mesh” connection that the “voltage” between the outer mains is “equal” to the “phase voltage,” but the “current” in the outer mains is  $1.73$  times the “phase current.”

With the “star” connection the “voltage” between the outer mains is  $1.73$  times the “phase voltage,” but the current in the outer mains is equal to the phase current.



## SINGLE-PHASE CIRCUITS: EFFECT OF SELF-INDUCTION AND CAPACITY AS REGARDS PHASE DIFFERENCE.

## II.—Starting of “Single-phase” Motors with Self-induction in an Auxiliary Circuit.

We can cause a “single-phase motor” to become “self-starting” if we supply it during starting with a second-phase current, which differs in relative phase with the main phase current. This condition can be attained by inserting in a branch “auxiliary”

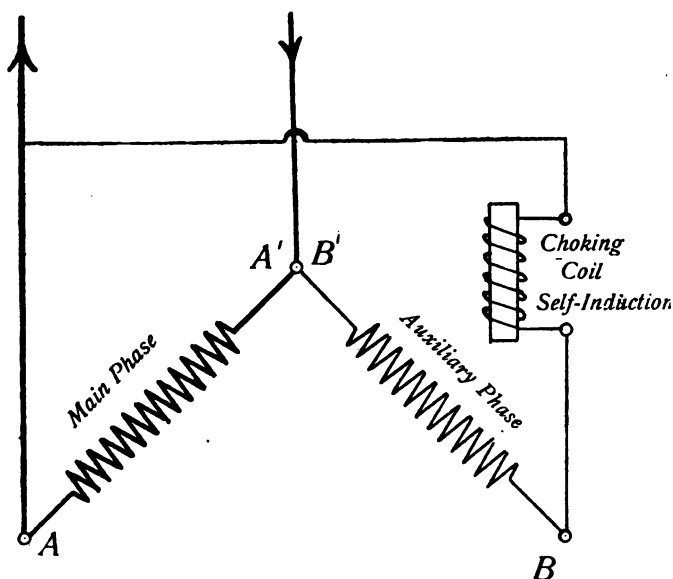


FIG. 83.—“Phase-difference” Method of Starting “Single-phase” Motors by means of Self-induction inserted in Circuit.

circuit a **choking-coil** which possesses **self-induction**. The arrangement is shown in *Fig. 83*. The “**main**” phase is connected directly to the mains; the “**auxiliary**” phase, which is a branch of the main circuit, is in series with a choking-coil. This produces a “**lagging effect**” (due to self-induction), and likewise a “**phase-difference**.” This gives the required condition to cause the motor to be **self-starting**. The single-phase motor

cannot, however, start under full load, but with only a part of its full normal load.

## 12.—Starting of “Single-phase” Motors with Capacity in an Auxiliary Circuit.

As we have just seen, we can cause a “phase difference” by utilising “self-induction” effects; likewise we can cause a phase difference by inserting “capacity” in an “auxiliary” circuit. The arrangement is shown in *Fig. 84*. As in the previous case, the

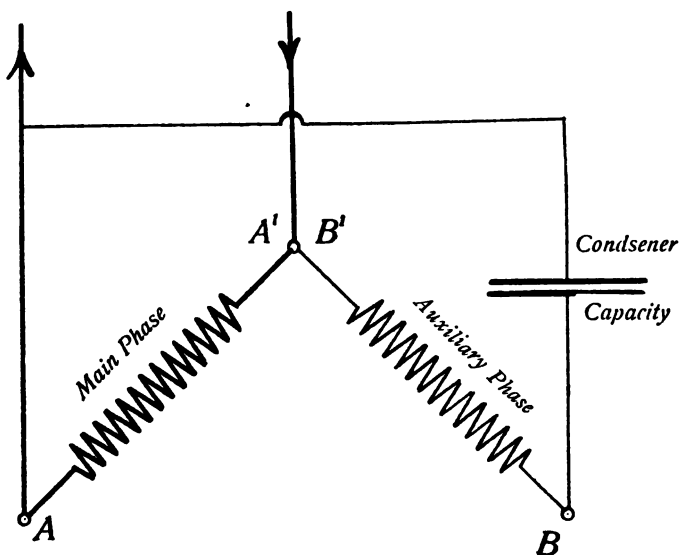


FIG. 84.—“Phase-difference” Method of Starting “Single-phase” Motors by means of Capacity inserted in the Circuit.

“auxiliary” circuit is a branch to the “main” circuit. In the “auxiliary” circuit is inserted a condenser. This produces a “leading effect” and likewise a “phase difference,” consequently the desired conditions.

Sometimes the effects of both induction and capacity are employed for starting a “single-phase” motor, a “choking-coil” being inserted in one circuit and a “condenser” in the other. We can also produce a phase difference by inserting “ohmic” resistance in one winding.

### 13.—Reversal of Alternating Current Motors, Single-phase.

When there is no auxiliary phase in circuit no change of connections is necessary, because it has no tendency to turn in one direction in preference to the other. It all depends on which direction it is rotated mechanically before the current is switched on. A “**single-phase**” induction motor with an “**auxiliary**” phase circuit behaves

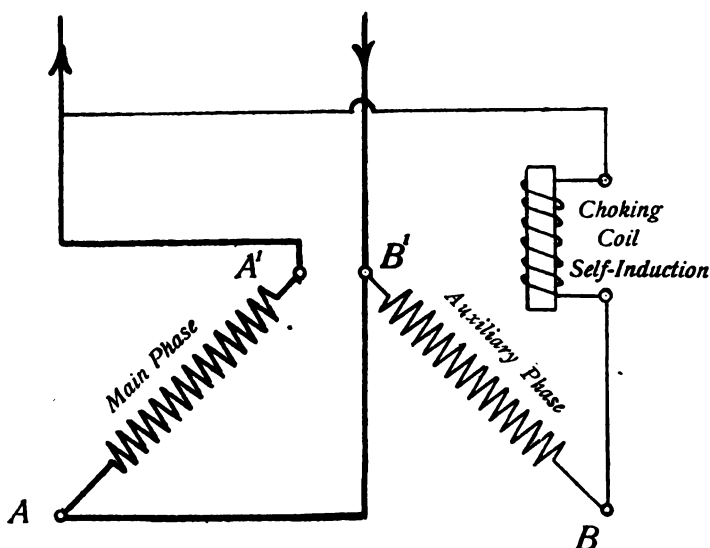


FIG. 85.—Method of Connections, so as to cause a Reversal of the Direction of Rotation of a “Single-phase” Motor.

like a “**two-phase**” motor. Figs. 83, 85, and 86 illustrate respectively the method of connecting the several terminals so as to get a **clockwise** rotation and a **counter-clockwise** rotation. There are shown two methods to get the counter-clockwise rotation. One is to alter the connections of the **main phase** (Fig. 85), and the other is to alter the connections of the **auxiliary phase** (Fig. 86).

With a “**three-phase**” motor the reversal of rotation may be effected by changing the ends of any two of the three mains fed by the alternating currents.

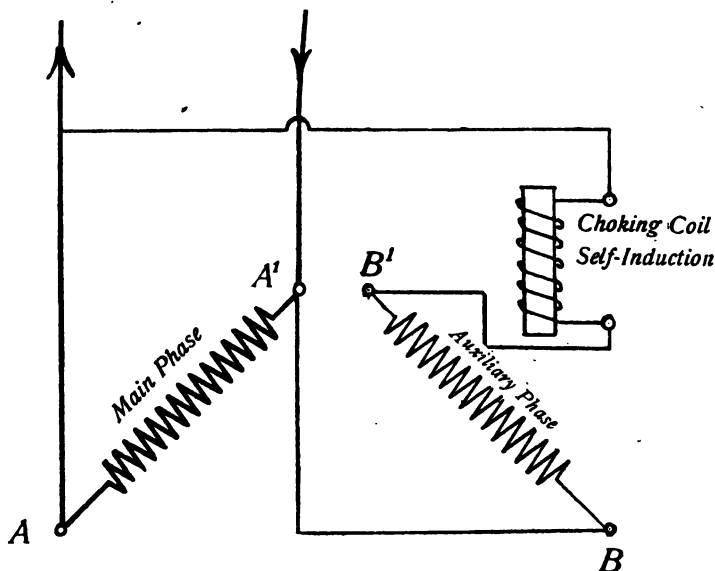


FIG. 86.—Another Method of Connections, so as to cause a Reversal of the Direction of Rotation of a "Single-phase" Motor.

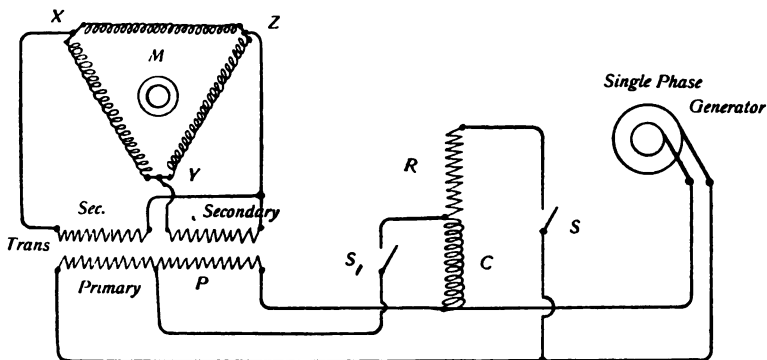


FIG. 87.—Method of Operating a "Three-phase" Motor on a "Single-phase" Current Supply.

#### 14.—Method of Operating a Three-phase Motor on a Single-phase Current Supply.

In Fig. 87 **M**. is a three-phase motor, **R**. a non-inductive resistance, **C**. self-induction coil; **S**. and **S**<sub>1</sub> are switches.

The motor **M** has the usual field winding, and a "three-phase"

winding on its "rotor." The "stator" is connected as shown. In the "primary" of the transformer is connected a "non-inductive" resistance,  $R$ , and a self-induction coil,  $C$ . By means of the switches  $S$  and  $S_1$  these can be put in and out of circuit. At starting they are put in circuit and produce a sufficient displacement of "phase" to start the motor. After the motor has started and attained speed, the switches  $S$  and  $S_1$  are opened, and the

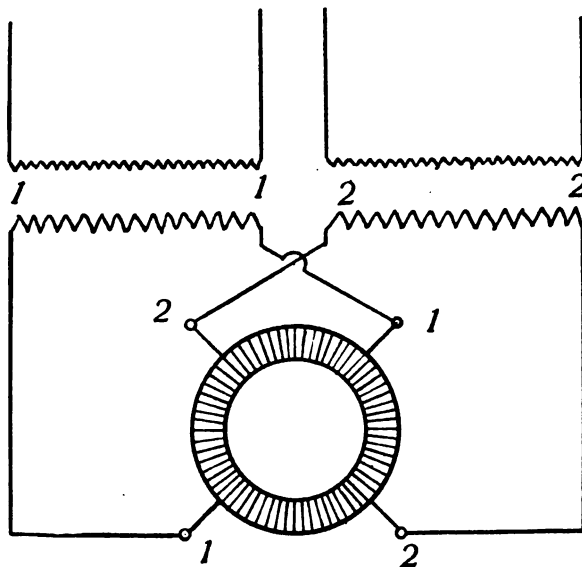


FIG. 88.—Rotary Converter and Transformer, Polyphase Connections. Two-phase Method.

reaction of the three-phase winding on the "rotor" induces a current in  $X.Y.Z.$  of the "stator" winding, the machine continuing to run as a three-phase motor, although supplied with single-phase current. The "stator" is connected as shown to the two ends and middle point of the secondary circuit of an ordinary split transformer.

#### 15.—Rotary Converter and Transformer Polyphase Connections, Two-phase, Three-phase, and Six-phase.

We can connect converters and transformers by different methods on two-phase, three-phase, and six-phase, circuits. In Fig. 88 is shown a two-phase arrangement. In Figs. 89, 90,

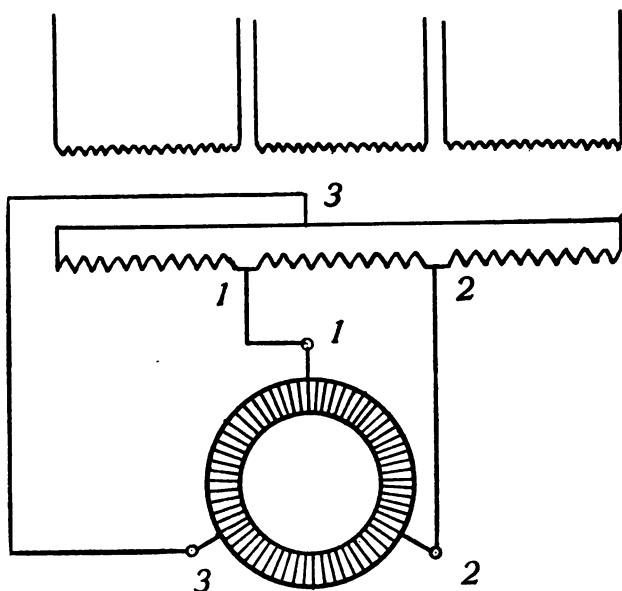


FIG. 89.—Rotary Converter and Transformer, Polyphase Connections. Three-phase Method.

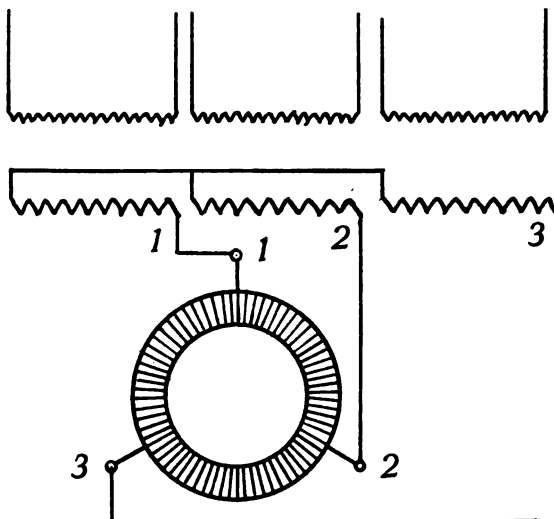


FIG. 90.—Rotary Converter and Transformer, Polyphase Connections. Three-phase, a Second Method.

and 91 are shown three different methods of connecting three-phase circuits, and in *Figs. 92, 93, 94, 95*, are shown four different methods

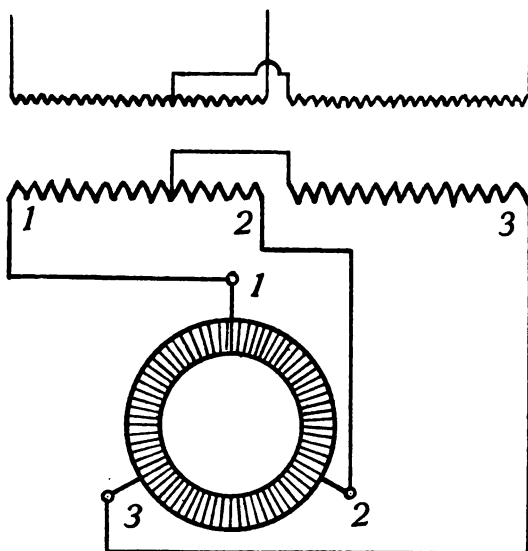


FIG. 91.—Rotary Converter and Transformer, Polyphase Connections. Three-phase, a Third Method.

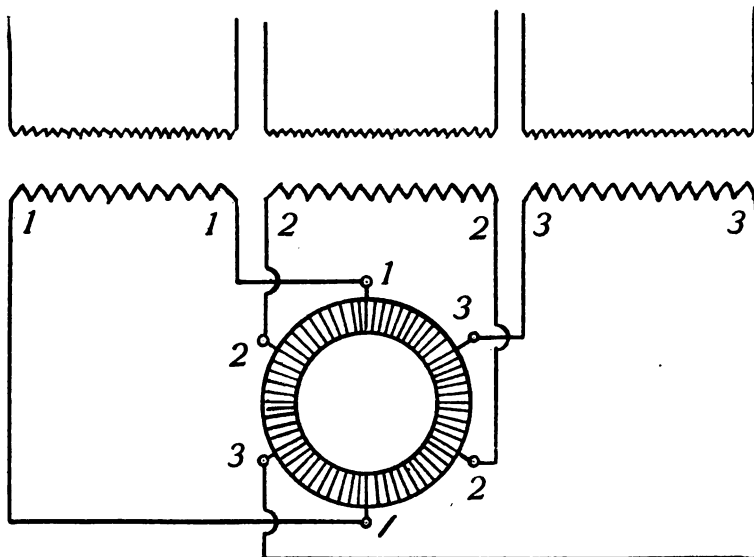


FIG. 92.—Rotary Converter and Transformer, Polyphase Connections. Six-phase Method.

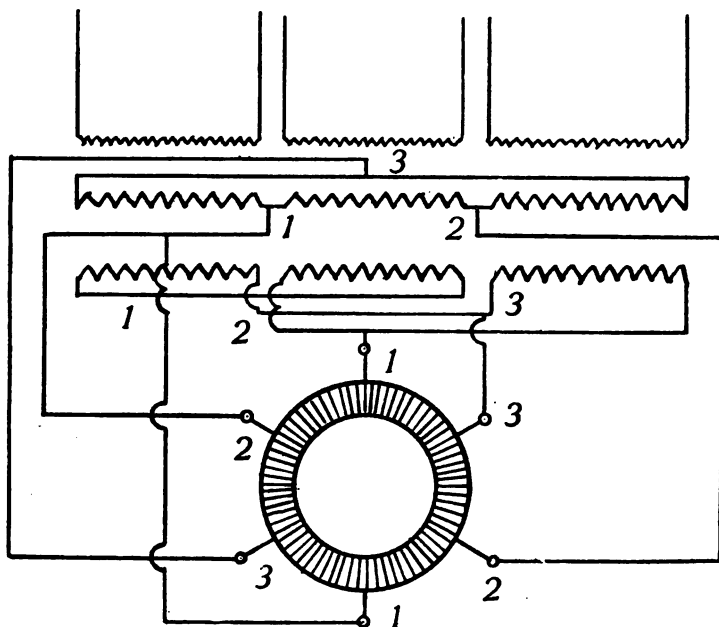


FIG. 93.—Rotary Converter and Transformer, Polyphase Connections. Six-phase, a Second Method.

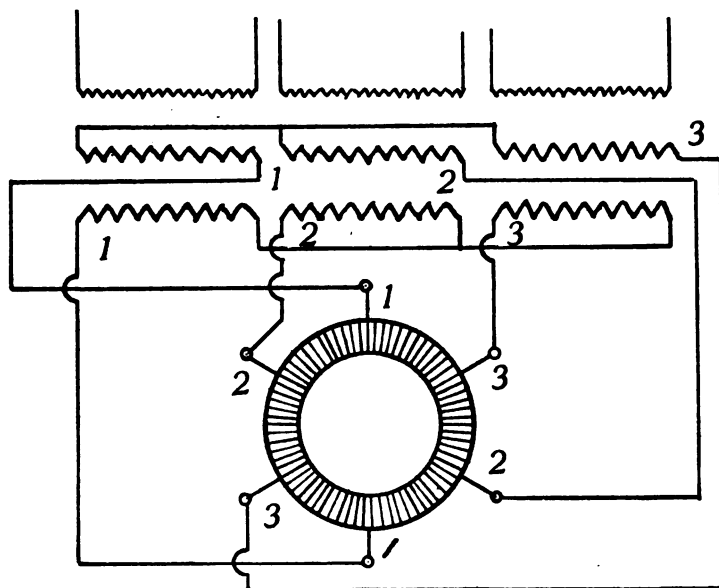


FIG. 94.—Rotary Converter and Transformer, Polyphase Connections. Six-phase, a Third Method.

of connecting up six-phase circuits. The connections explain themselves, and can be easily traced by means of the numerical numbers.

### 16.—Three-phase Distribution for Power and Lighting.

The advantage of the three-phase system of distribution for lighting and power work lies in the fact that it can be economically used for

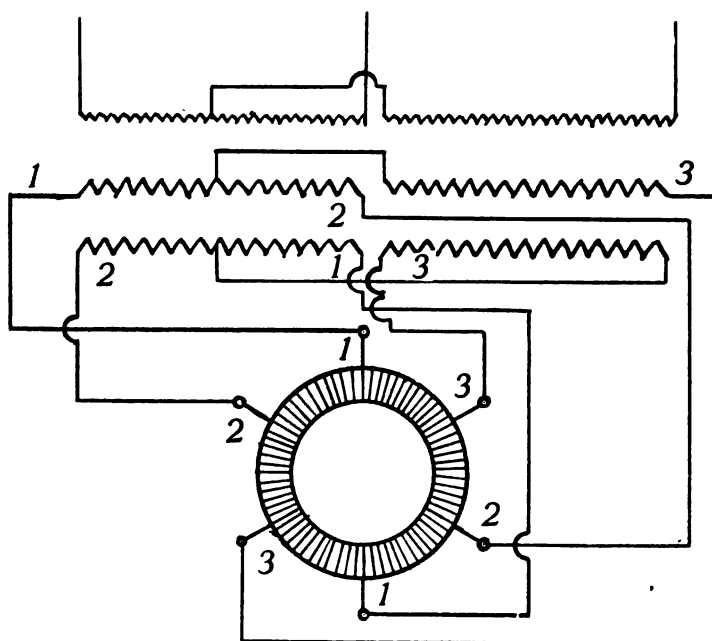


FIG. 95.—Rotary Converter and Transformer, Polyphase Connections. Six-phase, a Fourth Method.

transmission over considerable distances ; and thus a central station can do a large amount of business by supplying power to the outlying factories and mills, and in the supply of small lighting plants in the outlying districts. Another advantage lies in the fact that rotary converters can be operated. Also direct current for tramways or light railways can be produced, or direct currents may be required for lifts, hoists, &c., or for electrolytic work. The disadvantage of the two-phase system as compared with the three-phase, taking first

the two-phase three-wire system, is that for a definite amount of power to be transmitted at a definite pressure with a given loss, the amount of copper is considerably in excess of that required for the three-phase system under the same conditions; and, moreover, the system on inductive load is very difficult, if not practically impossible, to operate. The two-phase four-wire system possesses similar disadvantages to the two-phase three-wire as regards copper, but for transmission purposes solely is fairly satisfactory, while on inductive load the operation is difficult. It will be seen that such a system must be divided into groups or sets of groups, this division naturally overcoming many advantages, and, moreover, it becomes necessary to control each group by means of an induction regulator, as the load

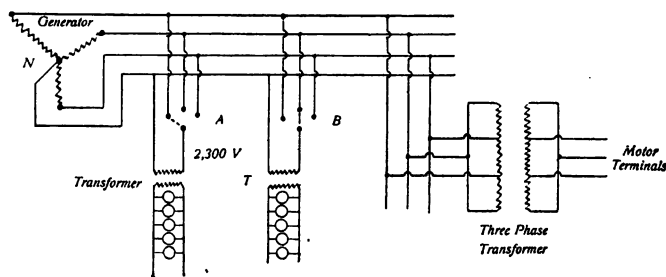


FIG. 96.—"Star" Method of Three-phase Distribution for Power and Lighting.

factor of the various groups may be entirely different, owing to the peculiarities of the different neighbourhoods into which the groups run. Consequently to keep constant pressure adjustments on each group requires careful attention. A three-phase generator is capable of taking 75 per cent. of its rated capacity on one phase with normal heating, and this single-phase load is to all intents and purposes as great as that which could be carried by a machine of equal weight and cost, if it had been designed for single-phase work. If the generator is connected "**star**" fashion, and is used as a **single-phase** machine, two-thirds of the windings are active, and the placing of these active coils is practically the same as would be arranged for, assuming the machine to be designed for single-phase working. In the first system of **three-phase** distribution for power and lighting the generators are connected "**star**" fashion with a fourth wire, taken from the neutral point *N*. (see *Fig. 96*). In this system the potential

between the line wires is 4,000 volts, and between any line wire and neutral is 2,300 volts. From the station three-phase feeders are run

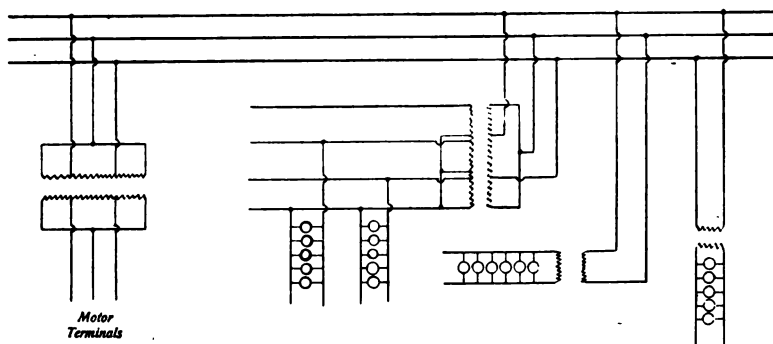


FIG. 97.—Low-tension Three-phase System for Power and Lighting.

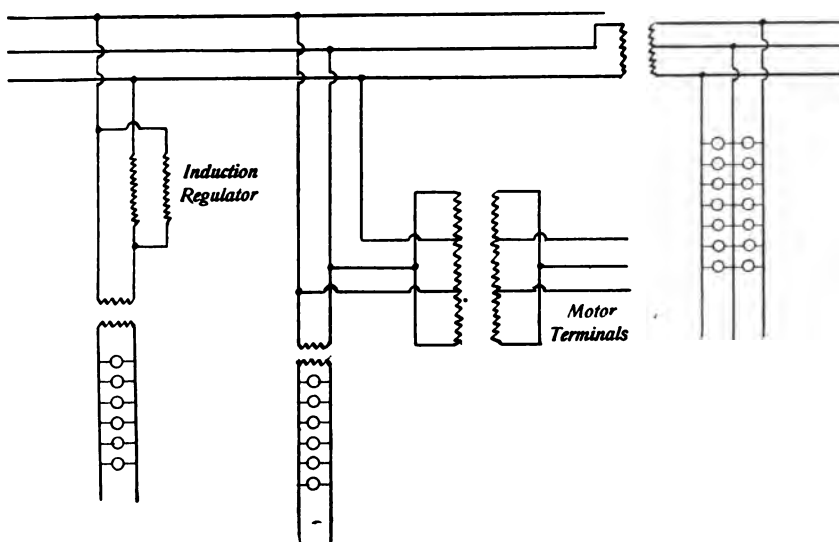


FIG. 98.—Low-tension Distribution by the Single-phase Three-wire System.

from which a three-phase network of 4,000 volts is run, so that consumers may be connected by short single-phase branches tapped off from one outside wire and the neutral. The necessary transformation is

done by means of an ordinary transformer wound for 2,300 volts primary, and the required voltage on the secondary. When "motors" are required to be operated they may be run from the three-phase mains, a three-phase transformer being used, which is a very good balancer. This system can be worked so that the motors can be operated with practically no effect on the lighting. It will be noticed that the feeders can be switched on to either of the three main wires and the neutral as shown at *A.* and *B.*

In *Fig. 97* is illustrated a low-tension three-phase system (four-wire). The primaries of the transformers are connected "**delta**"

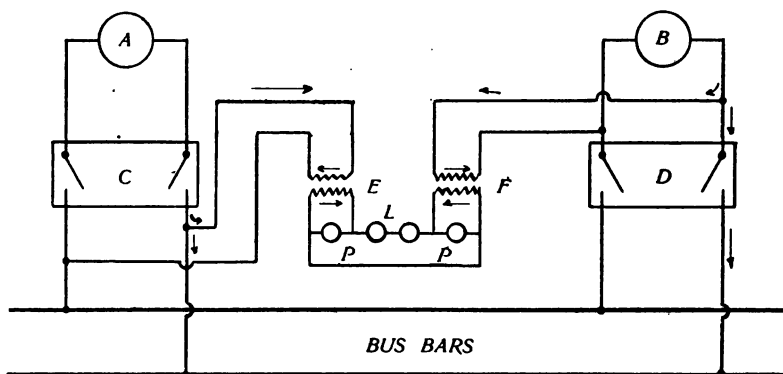


FIG. 99.—Single-phase Alternators in Parallel.

fashion, while the secondaries are connected "**star**" fashion, the neutral being connected to the common connection, and the lights being connected between one of the outside wires and the neutral wire; these are balanced as nearly as possible, while motors are connected to "**delta**" connected transformers across the three line wires. A third system (*Fig. 98*) is that of a low-tension distribution by the single-phase three-wire system, taken from one side of a three-phase generator.

### 17.—Working of Alternators in Parallel.

In *Fig. 99* is shown the connections of two 2,000 volt single-phase alternators with transformers used to reduce the E.M.F. to 100 volts

D.

H

for the synchronising lamps. **A.** and **B.** represent the machines, **C.** and **D.** the main switches, **E.** and **F.** the transformers, **L.** the synchronising lamps, and **P.P.** the pilot lamps. The transformer connections should be right. To synchronise follow out previous instructions, when the lamps **L.** will burn bright and steady, and the pilot lamps **P.P.** will be dark.

*Fig. 100* shows the connections of transformers and synchronising lamps sometimes used for starting synchronous motors or rotary

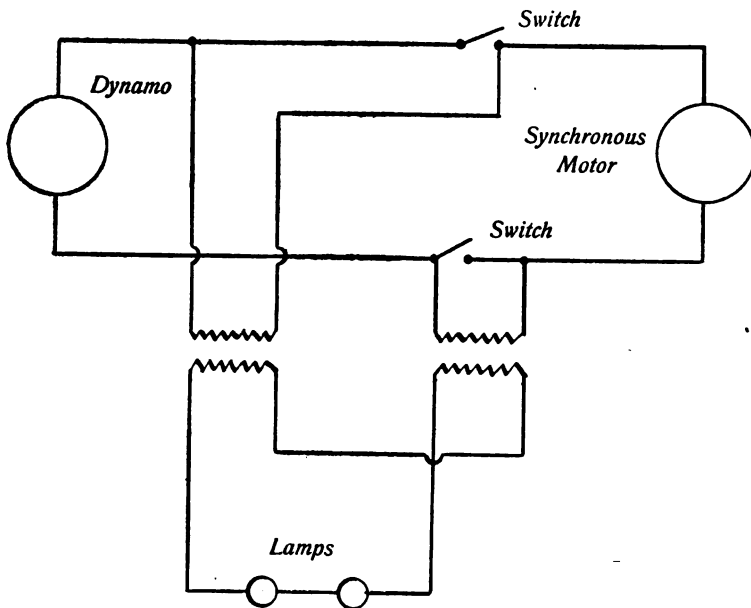


FIG. 100.—Method of starting Synchronous Motors or Rotary Converters.

converters. With this method of connection, however, it is necessary to have an additional switch to entirely open the circuit between the two machines, and the transformers are useless for any other purpose but synchronising.

In connecting two-phase generators for parallel running it is necessary to synchronise both phases the first time the machines are

paralleled. After they have once been "**phased-up**" synchronising one phase is sufficient. *Fig. 101* shows the connections for properly "**phasing up**" two two-phase generators, where **A.** and **B.** represent the generators, **C.** and **D.** the four-pole main switches, **E., F., G., H.** the transformers, and **L.L.** the synchronising lamps. To synchronise, if the machines are running at full speed and voltage, close switch **C.**: the lamps will flicker; then open switch **C.** and close switch **D.** to see if transformers are rightly connected. Then open switch **D.** and close

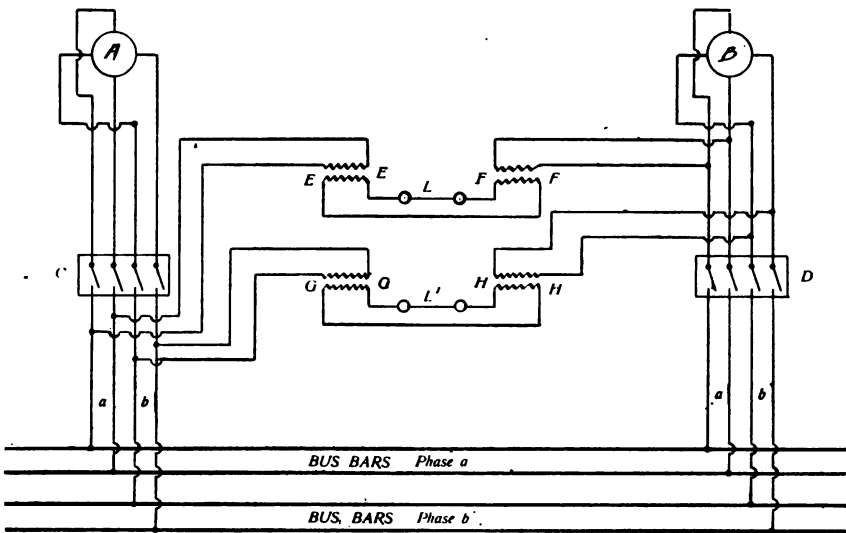


FIG. 101.—Paralleling Two "Two-phase" Generators.

switch **C.**; lamps **L.** and **L'** ought to glow brightly in unison. If one is bright while the other is dark the phases are connected wrong, and the lead wires of one phase on one machine should be reversed. Then test out synchronising apparatus as at first; if all the lamps glow in unison the machines may be thrown together without danger. The synchronising apparatus may then be removed from one of the phases, and the leads of the remaining transformer on machine **A.** transferred to the other side of the switch **C.**

*Fig. 102* shows the connections of **synchronising lamps** and **transformers** for paralleling two "**three-phase**" machines. To synchronise, proceed as in the case of the two-phase machines. If the lights on both phases do not come and go simultaneously when the machines are running at normal voltage, reverse two leads on one machine and try again. The right combination will readily be found. It is only necessary to "**phase-up**" two of the phases and the third will be right. After the machines have

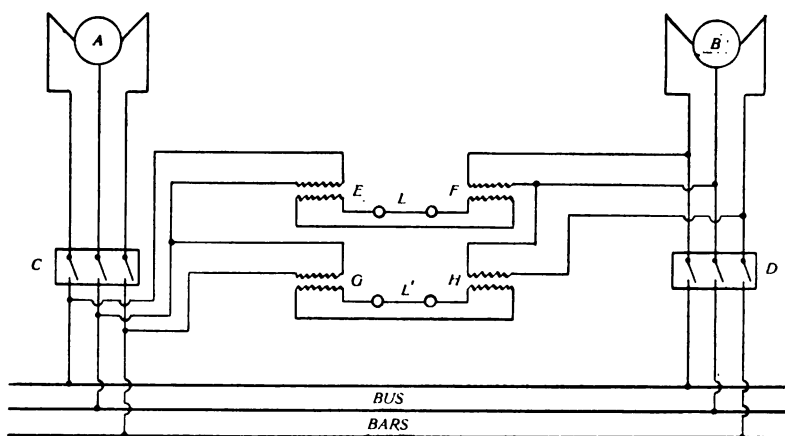


FIG. 102.—Paralleling Two "Three-phase" Generators.

once been paralleled, and the leads connected to the switchboard, synchronising one phase is sufficient, as in the case of the two-phase machine.

### 18.—Canal Haulage by Means of Electricity.

In the case of long canals, the power would be transmitted on the "**three-phase**" alternating current system at **high pressure** and at suitable points would be transformed down by means of stationary "**three-phase transformers**" and "**rotary converters**" to low-pressure direct current. *Fig. 103* explains the

method. *G* is the three-phase generator, *H.P.F.* are high-pressure feeders, *T.* are the transformers (three-phase), *R.C.* are rotary converters, *C.* is the electrical conductor, *L.* is the aerial railway line, which is bonded at intervals; to these bonds *B.B.B.* are

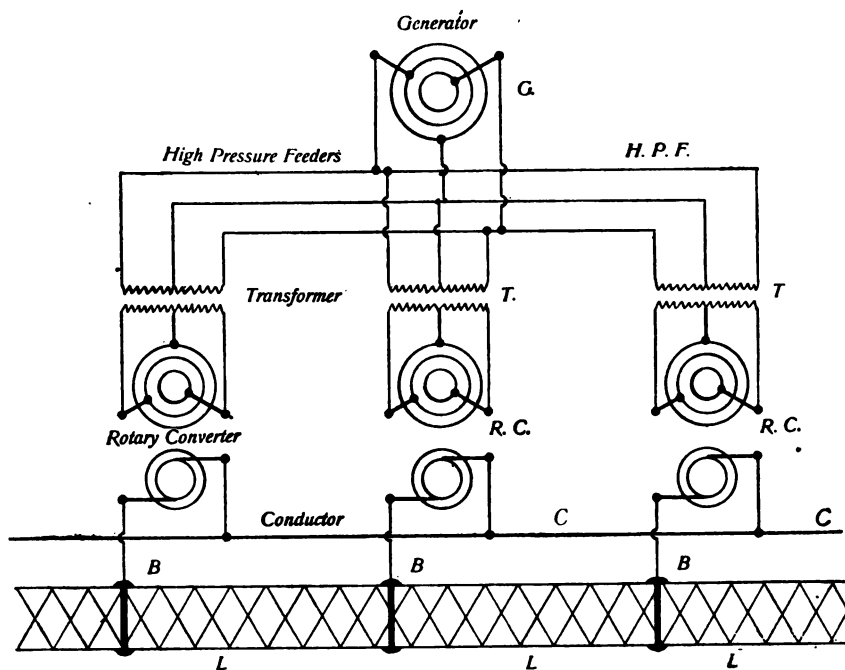
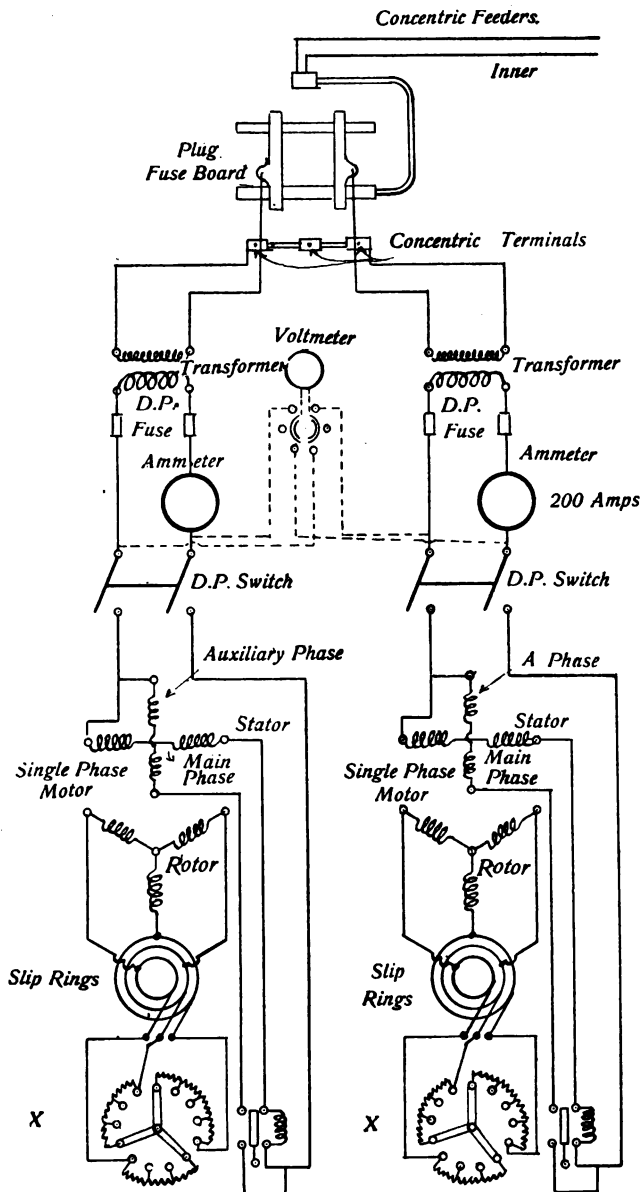


FIG. 103.—Transformer and Rotary Converters for Canal Haulage.

connected one of the terminals of the direct current portion of the rotary converters *R.C.*, which aerial line forms a return conductor of very low resistance. The voltage adopted for the transmission of the power would depend upon the length of the line and the position of the generating station—in all probability from 2,000 to 5,000 volts.

### 19.—Single-phase Pumping Plant.

Single-phase motors may be utilised for pumping purposes. *Fig. 104* illustrates the diagram of connections of the pumping plant as installed by the Hammersmith Vestry. The pumping plant consists of two single-phase motors of about 27 B.H.P. Each motor is fed by a separate 30 kilowatt transformer, which transforms the primary current of 2,200 volts and 50 cycles to a pressure of 220 volts, for which the motors are designed. The transformers are connected by concentric cables to a high-pressure fuse-board of the "Ferranti" standard oil brake type, the feeder between this and the power-house being a paper insulated, lead-covered, concentric cable, having its outer earthed; this can be plugged on to either transformer or to both at the fuse-board. The low-pressure switchboard, made by Messrs. Witting Bros., consists of two independent white marble panels, each containing an ammeter, a double-pole switch and a fuse, a voltmeter being common to both panels; these panels also contain the starting resistances and multiple contact switches *X.X.* for the rotor circuits of the motors. It will be seen from the connections that everything is in duplicate, each motor pump, with its transformer and switchgear, being independent and in parallel, so that a risk of total failure of condensing water is very remote. The motors are of Messrs. Witting Bros.' standard induction type, and are directly coupled to the pumps, no clutches being used. A special feature of these motors are their large starting torques and overload capacities, combined with good efficiency and high-power factor. A non-inductive rotor resistance is used at starting, which is inserted into the (star-connected) rotor windings through the intermediary of slip-rings and brushes; the latter are of laminated brass, while the slip-rings are of steel. A small auxiliary resistance is used in series with the running phase at starting; this is short circuited automatically by the auxiliary switch, which cuts out the starting phase when the speed has attained a certain value. As can be seen from the diagram of connections, this auxiliary switch, although electrically insulated from the hand-wheel and the three-way switch which cuts out the rotor resistances, is actuated mechanically by a projection from the hand-wheel, so that the motor is started simply by slowly turning the hand-wheel in one direction. The "**stator**" coils are arranged in a six-pole grouping, which gives a speed of 1,000 revolutions per minute at no load. The "**stator**" windings are buried in slots,



Starting Resistance, combined with Switch for Auxiliary Phase and Main Phase Resistance

FIG. 104.—Single-phase Pumping Plant.

insulated with micanite troughs, and as the three-phase "rotor" is wound in a similar way, the windings being keyed in by means of fibre wedges, these motors are practically indestructible.

## 20.—Practical Working of Rotary Converters.

Fig. 105 illustrates the diagram of connections with a "rotary converter," utilised on a three-phase circuit, also the neces-

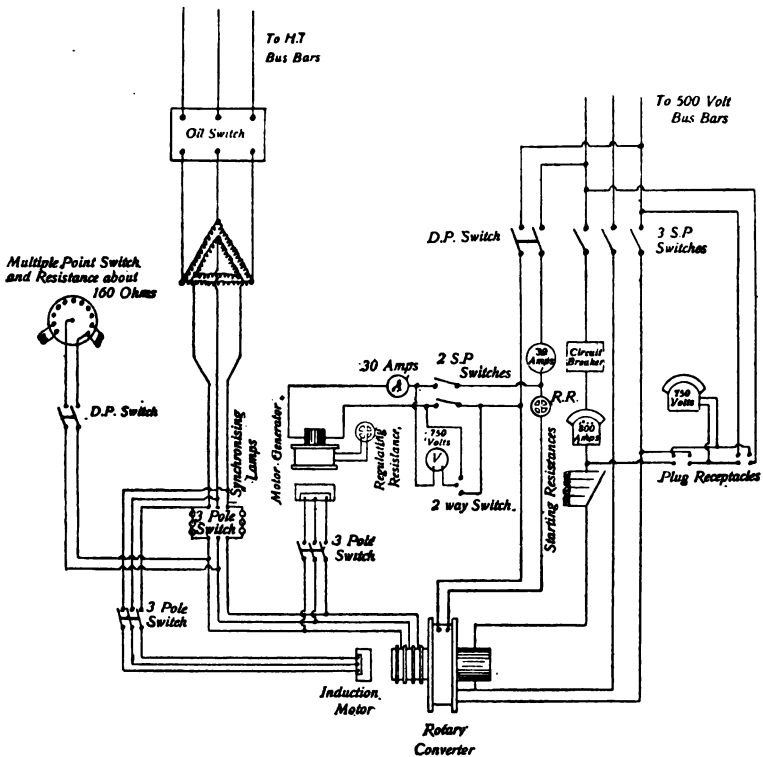


FIG. 105.—Rotary Converter on Three-phase Circuit.

sary apparatus is shown which is qualified in the drawing. This illustrates the great flexibility of the "rotary converter" when employed in a combined alternating and continuous current station; it is, of course, well understood that a "rotary converter" is reversible in its action, and can be employed for converting either

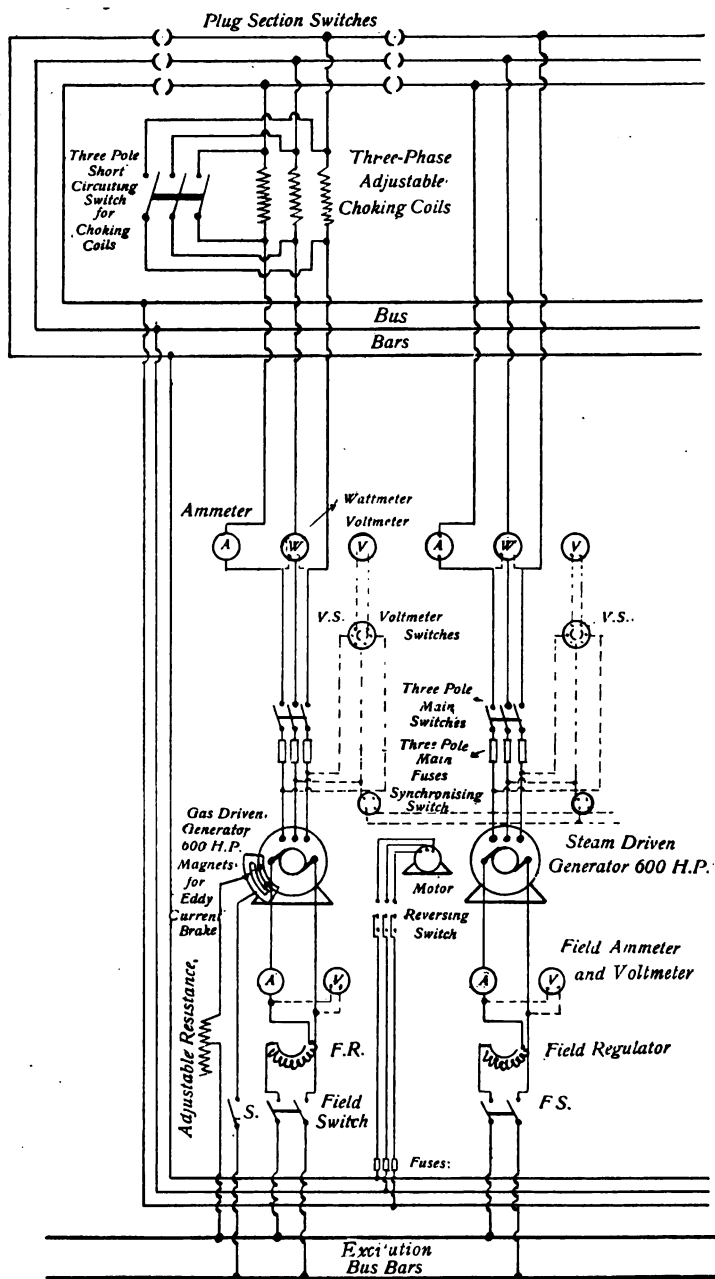


FIG. 106.—Polyphase Machinery Connections.

from alternating (single and polyphase) to direct current, and from direct to alternating. By the above arrangement the "rotary converter" can be used for running as a direct-current generator in parallel with one of the direct-current sets, being driven by a three-phase alternator, or for generating alternating current in the event of the alternator being shut down, and also for running in parallel with the alternator in times of excessive load.

## 21.—Polyphase Machinery.

*Fig. 106* illustrates the diagrams of connections required for a three-phase generator driven both by a gas engine and a steam engine. When connecting the gas-driven generator to the "bus" bars supplied by the steam-driven generators, a choking coil and an artificial load are used. The latter does not consist of a resistance connected to the generator, but of a special eddy-current brake acting on the fly-wheel, having a maximum braking effect of about 300 H.P. For work of this character, an artificial load is an absolute necessity, as an unloaded gas generator cannot be brought up to speed and thrown on the bus bars. The brake in question only absorbs a trifling amount of energy from the direct current mains, requires no additional space, can be regulated with ease and accuracy, and is an excellent mechanical job. Both the brake and the choking coil are put out of use as soon as the gas generator is working on the load; the (three-phase) choking coil is adjustable, and its function is simply to limit the synchronising currents which occur during the adjustments.

## 22.—Alternating Current Switchboard Connections at Hastings.

In *Figs. 107* and *108* are shown two very ingenious systems of switchboard connections. *Fig. 107* is the diagram of the main switchboard connections; the main switches controlling all the brush machines are of the water break type, but a horn break type of switch is used for controlling the turbo-alternator. No fuses or excess current cut-outs are used between the generators and the main bus bars. It is contended by some designers that no automatic device is necessary between modern alternating current-generators and the bus bars, as a faulty generator may be cut

out of circuit by the attendant in charge. This would be true if something corresponding to the central zero ammeter in continuous current stations could be obtained to indicate which generator was failing, but it usually happens that, when one of the generators fails, all the ammeters go hard over to their maximum reading, and the attendant may have nothing to guide him as to which generator has failed. In the United States this difficulty has been overcome by using a return current relay to close a local circuit through an indicating lamp, fixed directly over the operating switch controlling the failing generator. At Hastings, instead of the delicate relay

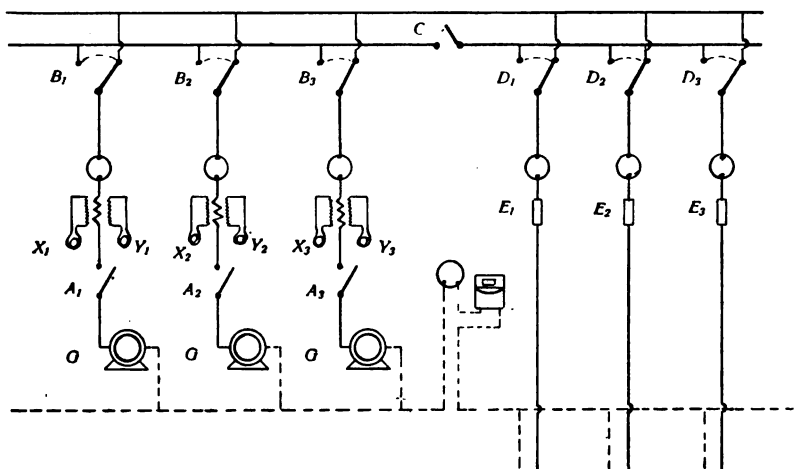


FIG. 107.—Alternating Current Switchboard Connections.

referred to, a small series transformer is inserted in the main circuit. This transformer is wound with two secondaries, and incandescent lamps, coloured red and green, are connected respectively across each secondary. The construction of the transformer is such, that when the generator is doing useful work the green lamp is lighted; but should the generator fail and receive current from the bus bars, the green lamp is extinguished and the red lamp lighted. There are no moving parts in connection with this most interesting and ingenious device, and consequently its behaviour is absolutely reliable.  $G.G.G.$  are the generators;  $A_1, A_2, A_3$ , water break switches;  $B_1, B_2, B_3$ , two-way switches;  $C$ , two-way water break

switch;  $D_1, D_2, D_3$ , two-way feeder switches;  $E_1, E_2, E_3$ , feeder fuses;  $X_1, X_2, X_3$ , red lamps;  $Y_1, Y_2, Y_3$ , green lamps.

Fig. 108 is a diagram of the Sub-station Connections.  $A, A_1$ , are high-pressure feeders;  $B$ , discriminating choking coil;  $C, C_1$ ,

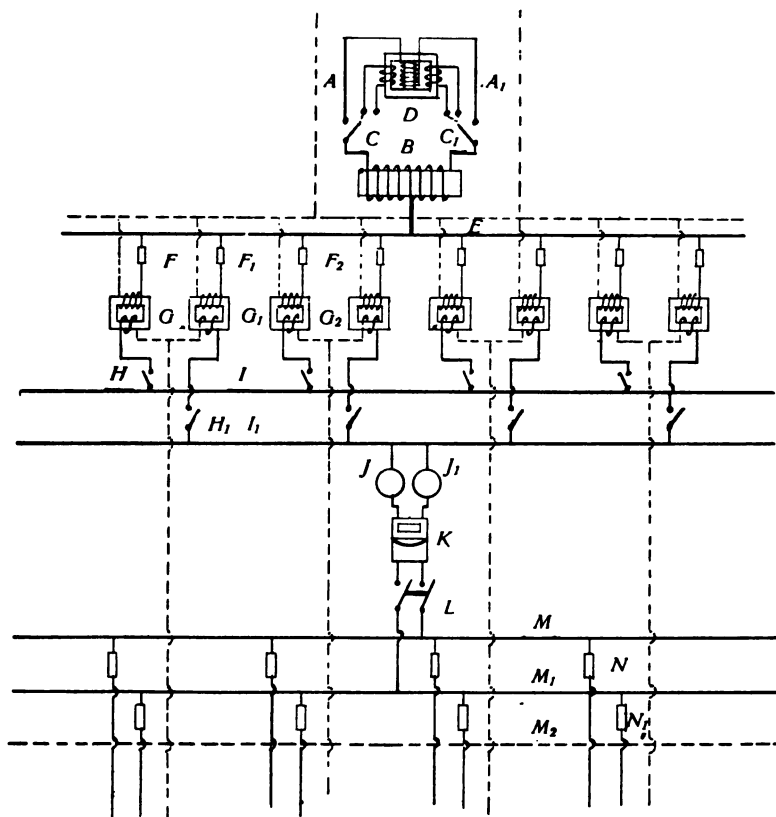


FIG. 108.—Alternating Current Sub-station Connections.

disconnecting switches;  $D$ , discriminating transformer;  $E$ , high-pressure bus bars;  $F, F_1, F_2$ , high-pressure fuses;  $G, G_1, G_2$ , transformers;  $H, H_1$ , low-pressure discriminating cut-outs;  $I, I_1$ , low-pressure bus bars;  $J, J_1$ , main ammeters;  $K$ , watt-hour meter;  $L$ , double-pole main switch;  $M, M_1, M_2$ , distributing bus bars;  $N, N_1$ , fuses. Each sub-station is fed by two independent high-pressure feeders in duplicate. By the above

arrangement, the liability of a failure on one feeder causing a break-down on the other feeder has been entirely obviated, as an excessive current is prevented from flowing from one feeder to the other without any form of switching device whatever. For this purpose the feeders at the distributing station end are connected together through a choking coil, consisting of a few turns of insulated copper wire wound on an iron core. The supply of the load on the sub-station is tapped off from the centre of this winding. Under normal conditions, the current being supplied to the sub-station is divided equally between the two feeders, and its tendency is to magnetise the iron in opposite directions; as the two magnetising forces just neutralise each other, there will be no magnetism in the core, and consequently no inductive drop in the windings. Should one of the feeders break down, current will tend to return towards the fault from the healthy feeder, but this current will circulate round the core of the discriminating choking coil in one direction only. As a consequence the core will at once become magnetised, and the counter electromotive force, induced in the coil, will entirely prevent an excessive current flowing from the healthy feeder to the faulty feeder. Providing there is a short circuit, it is desirable that the feeder should be disconnected as soon as possible. This may be very simply effected by means of the discriminating transformer D. The secondaries are, in this case, short-circuited by copper fuse wires, which support the weighted levers that serve, when released, to disconnect the respective feeders from the choking coil. The high-pressure primary of this transformer is connected between the duplicate feeders. It will be obvious that under normal conditions there will be no difference of potential between the terminals of this winding, but should a feeder fail, current will flow from the healthy feeder to the faulty feeder through the primary winding of this transformer, and the construction of the transformer is such that a heavy current will be induced only in one of the secondary windings, namely, that which controls the switch in circuit with the faulty feeder.

### 23. — Application of Polyphase Currents to Electric Traction.

The method of adopting polyphase currents (through the intermediary of three-phase rotary converters) to the requirements of

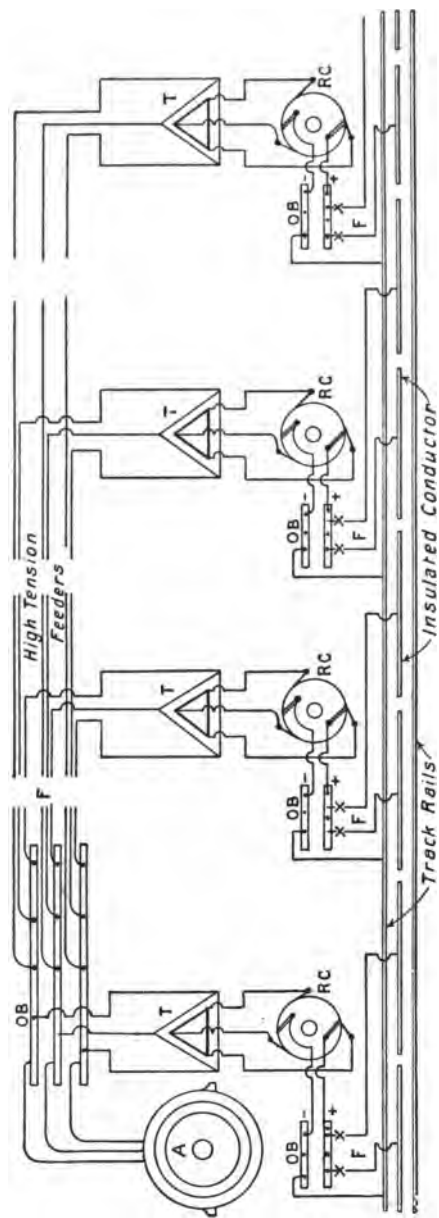


FIG. 109.—Polyphase Currents applied to Electric Traction.

modern electric traction, is shown, diagrammatically, in essentials in *Fig. 109* (taken from Tyson Sewell's "Elements of Electrical Engineering," Crosby Lockwood). The illustration needs but little explanation. *A.* represents a three-phase alternator, generating at say 5,000 volts. *T.T.T.* are three-phase transformers, or three single-phase transformers, one on each phase, in sub-stations along the line, which transform down to about 300 volts. *R.C.* represent rotary converters, converting from three-phase to direct current at 500 volts. *F.F.* are feeders supplying direct current to the line or third rail, which is divided into sections. The current returns by the track rails, which are electrically connected or "bonded" by stout copper rail bonds, and these are connected to the negative bus bars at intervals.





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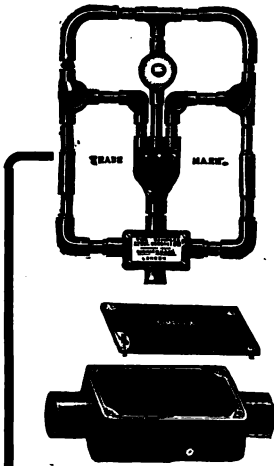
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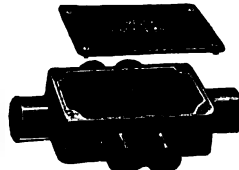


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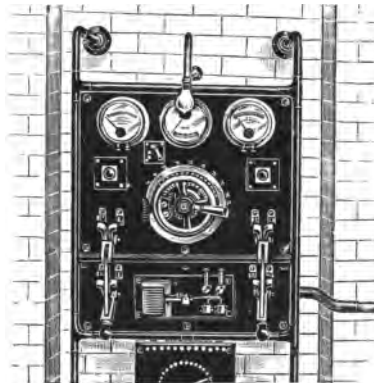
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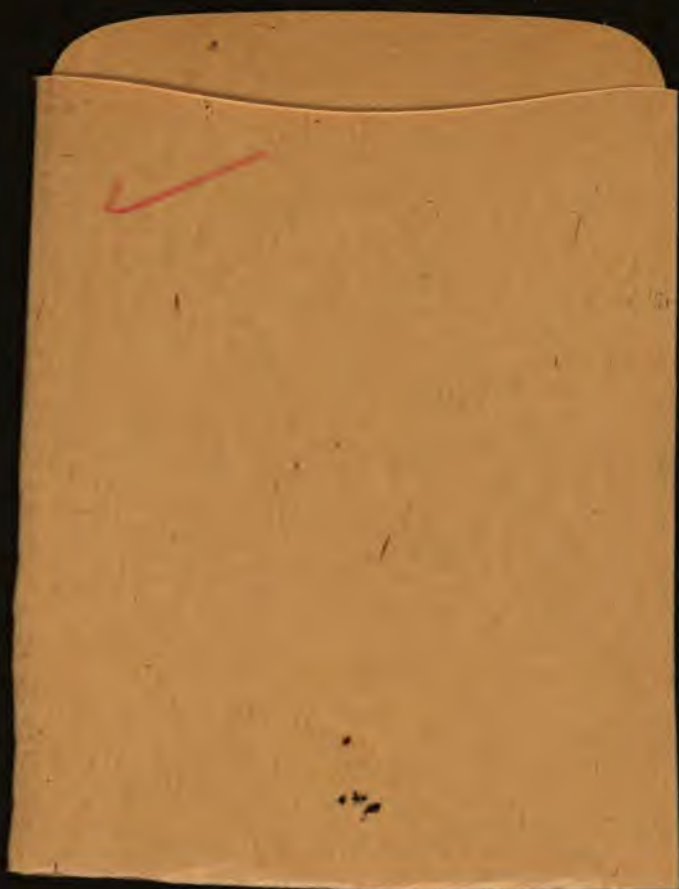
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